Energy Efficiency in Office Technology

by
Cyane Bemiss Dandridge
B. Arts, Reed College
Portland, Oregon
June 1989

SUBMITTED TO THE DEPARTMENT OF ARCHITECTURE
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
MASTER OF SCIENCE IN BUILDING TECHNOLOGY
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
February 1994

Signature of the author ______________________________
Cyane Bemiss Dandridge, Department of Architecture
January 14, 1994

Certified by ______________________________
Leslie K. Norford
Associate Professor of Building Technology
Thesis Supervisor

Accepted by ______________________________
Leon R. Glicksman
Professor of Building Technology
Chairman, Department Committee on Graduate Students

Energy Efficiency in Office Technology

by

Cyane Bemiss Dandridge

Submitted to the Department of Architecture on January 14, 1994
in partial fulfillment of the requirements for the Degree of
Master of Science in Building Technology

ABSTRACT

This thesis, directed toward a wide variety of persons interested in energy efficiency issues with office technology, explores several issues relating to reducing energy use and improving energy efficiency of office equipment. Chapter 2 compares policies and programs in several European countries and the United States that could enhance the energy efficiency of office technology. Different programs are examined, including federal government programs where in some cases target values for power usage of office equipment have already been set. Large customer procurement programs, industry involvement, with emphasis on voluntary labeling programs, and research projects are also examined. Procedures that provide energy consumption measurements of various types of equipment are important for providing information to emerging procurement programs. Two sets of proposed test procedures for testing energy consumption of copiers, fax machines and printers are examined and compared.

In Chapter 3, comparisons are made of the electrical power and energy used by computers, displays, copiers, printers and facsimile machines, both while operating and while idle. Technology options for reduced energy and power consumption and improved energy efficiency are examined. As the capability of office equipment has increased, there has been a trend toward increased electrical power requirements and energy consumption while equipment is in active operation. Computer power continues to grow rapidly. These factors will combine to exert an upward pressure for electrical power. However, some emerging technologies are lessening or in some cases reversing this trend, with little or no penalty in performance or production. The overall balance between increased service and efficiency is uncertain. Chapter 3 also examines the embodied energy of paper and office equipment. I compare it to the total energy required to produce a printed page of information, or required over the lifetime of the machine.

Many difficulties were encountered in collecting and comparing data on power requirements of various machines. Procedures for testing the energy usage of office equipment are needed to make valid comparisons between machines. This thesis describes in Chapter 4, modifications to the procedure issued by the American Society for Testing and Materials (ASTM) to test energy consumption in copiers, to account for energy saver modes and double-sided copying. It also presents new procedures submitted to the ASTM committee for printers and fax machines. A fourth procedure is also presented here, one to test the energy consumption of personal computers.

Typically, office equipment is not in use for much of the time it is turned on. Use of power management in office equipment can considerably decrease overall energy consumption.

While energy saver modes are more prevalent in copiers, those printers that have incorporated this feature achieve more dramatic power reductions. Fax machines do not seem to utilize this technology at all, even though many have high power consumption when they are idle. How energy saving modes effect the overall energy consumption of machines is largely determined by operating profiles of the machines. The effect of operating profiles on energy usage with imaging equipment has not yet been examined. Methods of determining operating profiles of office equipment are presented in Chapter 5. A comparison is made between the energy use predicted by the ASTM procedures, energy use predicted by the ASTM procedures and actual operating profiles, and the actual energy usage of several copiers and printers. For copiers, the ASTM rated energy use per page was from 10-161% different from the actual measured energy use per page. The use of the ASTM method with the measured operating profiles of the machine gave a 7-22% difference in energy use per page. For printers, the rated values using the ASTM method gave 61-317% difference from the actual measured energy use per page, while using actual usage profiles with the ASTM method gave 0-6% difference.

This thesis provides information on a variety of subject in the area of energy use and energy efficiency in office technology. The results provide information for emerging programs and provide a strong basis for a variety of further research.

Thesis Supervisor: Leslie K. Norford.
Title: Associate Professor of Building Technology

Acknowledgments

This work represents a portion of a project to assess and enhance the efficiency of electronic office equipment. We were funded as a subcontractor by the American Council for an Energy-Efficient Economy (ACEEE), which in turn has been funded by a consortium of utilities and government agencies led by the Electric Power Research Institute (EPRI). Funding partners of the consortium include EPRI, the New York State Energy Research and Development Authority, California Institute for Energy Efficiency, Consolidated Edison Company, Ontario Hydro, Pacific Gas and Electric Company, Southern California Edison Company, Wisconsin Center for Demand-Side Research, U.S. Department of Energy, and U.S. Environmental Protection Agency.

Substantial advice and helpful criticisms of several of the chapters included here were made by Loretta Smith and Steve Nadel of ACEEE, Marc Ledbetter of Battelle/PNL, and Jeff Harris of Lawrence Berkeley Laboratory. Thanks especially to Jeff and Les Norford, who motivated a wide range of the work in this area, and provided the momentum that encouraged most of the growth in this field. Jacques Roturier provided the opportunity for me to do research in this field at the University of Bordeaux, France for six months. The travel opportunities he provided were invaluable to this research. Leon Glicksman spent a lot of time reading this thesis, and added some valuable insight to future work. Bernard Aebischier provided a large portion of the information on Switzerland, provided in Chapter 2, while Olof Molinder provided a large portion of the information on Sweden.

Les Norford, my advisor on this project, put up with me throughout the many paulinesque trials and tribulations. He offered advise, support, and read through the many drafts of this work. All 14 thousand of them. Well, it felt like it.

Ward gave me all the support, humor and insight I could ask for, and more. I would never have done any of this without him. Thanks Robin for some great jokes, good distractions, perspective, understanding and motivation. And of course I wouldn't have been here, or have gotten this far without mom and dad.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Today, energy efficiency has become on of the world's leading energy options. In a poll taken in 1987, both public interest leaders and industry leader indicated that they favor energy-efficient technologies as an energy option, over all other energy options mentioned in the poll, including solar energy, natural gas, and oil (Farhar 1993). While much attention has been paid to efficiency in lighting and refrigeration, energy efficiency in office technology is only just becoming a focus for many utility demand forecasters, standard setting and enforcement organizations, procurement officers, and policy makers.

It is quickly becoming a necessary part of the new energy option, energy efficiency. In commercial and institutional buildings, office equipment is one of the fastest growing electrical loads in the United States and possibly in the world. One study showed that the peak summer demand due to office equipment in several buildings in the United States had, from 1985 to 1988 grown from .25 W/ft^2 to .37 W/ft^2. Energy efficiency issues associated with lighting have obtained considerable attention over the past few years. However, the load due to lighting dropped in those three years from 1.5 W/ft^2 to 1.44 W/ft^2 (Michaels et al. 1990). A study of office buildings in California showed that office equipment consumed 6 percent of commercial-sector electricity use in 1989 and could require 11 percent of the total in 2011 (Piette et al. 1991). In Switzerland, office equipment uses 5 percent of the power used in the service sector (Prechtl 1993). None of these calculations include the load due to the power needed for cooling in the building. With increased use of office equipment, there will undeniably be an increased need for cooling.

Office buildings in the United States in 1989 accounted for 12 billion square feet of building space. In one study, the projected energy use per area of floor space in 1989 was 2 kWh/ft^2 per year (Piette et al. 1991). Therefore, the energy use due to office equipment in 1989 was 24 TWh/year. If a typical 1 GW baseload power plant is available 85 % of the time, and produces full power when running, it generates 7.5 TWh/year. Using the above information, the load due to office equipment for 1989 was equivalent to 3.2 power plants. Using an estimated $.075/kWh, in 1989, electrical energy costs due to office equipment were 1.8 trillion dollars. This is an estimate only for commercial office buildings, and does not include office equipment in any other type of building, commercial or residential.

In this thesis, I will present information on energy-efficient policies and technical options for office equipment. Of note here is the Environmental Protection Agency's Energy Star program, a voluntary program with manufacturers which aims at lowering the power consumption of computers, displays and printers. This program was announced in 1992, with application of the program a year later. It addresses the standby power usage of the equipment; in order to comply with the program, units must use no higher than a maximum level in standby. By the EPA's calculations, this program could give a 57 percent savings per unit. By using EPA's estimated 65 percent market penetration (U.S. State Department 1992), in 1989 office equipment would have required only 2 power plants and the expenditure of 1.1 trillion dollars. By using a projection done by the same study (Piette et al. 1991), in 2011, the load due to office equipment should double. Assuming the same savings and a 85 percent market penetration, 3.3 power plants would be used in 2011, versus the assumed 6.4 without the EPA's program. According to these estimates, 1.9 trillion dollars would be used, a savings of 1.7 trillion dollars from the projected 3.6 trillion dollars.

In order to satisfy the EPA's program, manufacturers had to lower the power consumption in standby. The most viable option to lower the power consumption was to employ power management. When a machine is idle after a specified amount of time, the unit will go into a lower power state, and in most cases return to a ready state when users signal by pressing a key or mouse button. By one survey (Tiller 1992), computers sit idle for 30 percent of the time they are on. Power management is not the only option available to lower office equipment energy use. Lowering the total power consumption would be an even better option, since it would address the times the machine is not sitting idle as well. In some cases this is nearly impossible given the performance required now by most users, which is why the EPA did not address the full power required by the unit. But with the use of equipment like laptop computers and ink-jet imaging devices, total power consumption of the machine can be lowered.

There are several other emerging programs that concentrate on these issues. Since I spent the spring of 1993 in Europe, I was in a good position to examine many of these emerging programs. Chapter 2 is a policy assessment of some of the emerging programs from Europe, Japan and the United States. I traveled to meetings and conferences in the US, Switzerland, the Netherlands, Denmark, Sweden and France. I spoke with parties from each of these countries, and from Great Britain. Initially, I prepared the report to provide information to the European Community on what was happening in the United States, in order to give them some foresight into the problem. I discovered that two European countries already have programs in place. Ideally then the report should be used by interested parties in both the United States and Europe, in order to coordinate activities. There must be a more concerted effort on the part of each country to work together on emerging programs, because the majority of office equipment manufacturers are based internationally. If a relatively small country like Switzerland or Sweden tries to push forward energy saving specifications without any other support behind them, it is likely manufacturers will not act. Recently, Japan announced its willingness to participate in an international labeling program similar to the Energy Star program. This has only happened after many other countries have shown their support. The General Services Administration, which purchases 10 percent of all office equipment sold in the United States, added its buying power to the program with its support.

Chapter 2 is also intended for the use of researchers and groups interested in investigating possible areas of savings in this area. By having information about programs in many different countries in one paper, I hoped to avoid duplication of effort. So far, two different sets of test procedures have been prepared, because of this lack of communication. Also, many groups are beginning to gather information for a data base for office equipment. I hope that this chapter will provide interested parties in putting information together to prepare one large data base, rather than many small ones.

This thesis includes as Chapter 3 a much needed technical assessment of office equipment. There have been very few studies done in this area. Norford et. al. (1990) and the Rocky Mountain Institute (Lovins et. al. 1990) did studies, but since the technology in this area changes so fast, some of the information presented is no longer applicable. Chapter 3 focuses not only on power and energy usage for office equipment, but also attempts to examine many the current and future trends in copiers, faxes, printers, personal computers and monitors. It provides an overview of available energy-efficient technologies, such as ink jet imaging devices, and how future technology is going to effect energy use. In particular, I included a section on combined devices and the influence networking and multimedia might have on the future energy use in an office. The chapter explores options for reducing energy use and improving energy efficiency, in some cases through the use of power management options, or the reduction of paper use. Comparisons are made of the electrical power and energy used by computers, displays, copiers, printers and facsimile machines, both while operating and while idle.

There is also a section on environmental issues associated with office equipment. This is a growing area of concern. Landfills are overflowing, and much equipment that might still be usable is just being thrown away. Some companies are trying to take back equipment to reuse and recycle, but are only able to get 5 percent of their equipment back. I talked to several manufacturers in both the United States and in Europe on what their companies are doing for this issue. I also discuss in detail the issue of paper use by imaging equipment, and the use of recycled paper.

Collecting information for the technical assessment of office equipment was very difficult. I made many phone calls to manufacturers to get energy consumption of equipment. This was nearly impossible; either there were no data at all, or the only numbers available were nameplate ratings. Nameplate ratings only give the peak power consumption of the machine, not the overall power consumption. When a variety of numbers were available, the technical assistants I had contacted could not tell me how the machines were tested, or what test procedure was used when testing the equipment. Finally, I found that the State of California was using a 1987 ASTM procedure for testing the energy consumption for copiers (ASTM 1987). However, this procedure didn't provide a good method for testing energy consumption, since it lacked several options that are currently available on most copiers. Therefore, I revised it and used the numbers from the California data and numbers from manufacturers to determine the energy consumption for copiers. I attempted to do the same thing for printers, but the data were even more scant.

In order to provide information many programs are requiring, standard procedures that give definitive ways of providing that information are imperative. If manufacturers test machines in different ways, values for power consumption will differ. For example, a copier has spikes of power usage when it heats up the fuser; depending on when the machine is tested, or for how long, the number for standby or operating power will vary.

It is important to have standard procedures, and it is important for them to be internationally recognized as standard. If manufacturers have to satisfy set limits of an internationally recognized program such as the Energy Star program, but do not have a standard test procedure to use, some may report that they satisfy the programs limits, even though the machine, when tested by a different procedure, is found to have power levels too high to satisfy the program.

In Chapter four, I present four different test procedures I wrote for copiers, printers, fax machines and personal computers. Users of these test procedures are required to follow an exact method, testing the piece of equipment in each of several modes. The energy requirement of each mode, and the energy requirement per month and (in the case of imaging equipment) per imaged page is reported. These values can also easily become the average power usage over an hour period. These numbers can be converted for use to provide a variety of information, including energy use or cost over a year or over the life of the equipment. These values should not be used to determine actual energy consumption of a machine in use in a particular office. These values are for comparative purposes, to satisfy a variety of programs aimed at providing information to users.

The imaging test procedures were written under the auspices of the American Society for Testing and Materials (ASTM). I joined the committee in 1992, and first revised an existing copier test procedure. The printer and fax procedures followed. In the fall of 1993, I presented the test procedures to the Council for Office Products Energy Efficiency (COPEE), which plans to adopt them for its testing and information program for office equipment required by the 1992 U.S. Energy Policy Act. I am currently working with COPEE on using my procedures for their program. I developed the personal computer test in response to this program. I based it as closely as possible on the ASTM test procedures for ease of use.

Surrounding many of the emerging programs is the need for providing to users not only comparative values of energy use for like machines, but also the actual energy usage of a machine. When trying to determine the energy consumption of an office building, actual usage values are necessary. Chapter 5 is an assessment of two of the test procedures presented in Chapter 4, in order to test the accuracy of the procedures, and to look at how they compare with actual operating profiles of machines.

I took measurements of the energy consumption of several copiers in printers in both Europe and the United States. Measurements were taken with a watt-hour meter that printed out the average power every 15 minutes. I also used methods to record the usage pattern of the machine, and then to make several different comparisons. After obtaining the total energy consumption of the machine and the total amount of imaged pages, a figure for energy use per page could be calculated. Using the ASTM method, I reached a predicted value for total energy use and energy use per imaged page, by using the method as recommended. These values were compared to the actual measured values. Each machine was also tested for the imaging energy use with the imaging volume actually used by the machine that was tested. All three values gave a valuable insight into both operating profiles of particular machines, and to the variety of ways the ASTM test procedures can be used. In most cases, when using actual usage profiles and the ASTM procedures I predicted energy consumption very close to the actual energy usage of the machine.

Chapter 5 can be used as a definitive method for determining the actual energy use of machines. The data given are not extensive, therefore, no statistical analysis can be made from the information provided in Chapter 5. Energy analysts will be able to use the methods I laid out, in order to determine usage cycles. Use of the data provided on individual machines will be useful in determining the method used, and developing a future in depth study of the operating profiles of imaging equipment.

Each chapter of this thesis can be used for different purposes. Chapter two is a policy assessment and Chapter three is a technology assessment. Chapter four provide methods that serve emerging policies, and ease the gathering of information for a technical assessment. Chapter five provides an insight into how the test procedures of Chapter four can be used. I hope to provide with this thesis some valuable insights into an issue that is getting an increased amount of attention.

Chapter 2: Energy Policies for Energy Efficiency in Office Technology: Case Studies From Europe, Japan and the United States

I. Introduction

Energy efficiency in office technology is becoming an important topic in many sectors around the world. Because it is growing so quickly, there are many problems associated with this fast growth. While information within individual countries has been readily available, little information has so far has been passed between countries. Duplication of effort often results, and in some cases when information is passed by word of mouth, reports are misinterpreted. Language and cultural barriers may account for some of these problems, but I believe that the distance between interested parties accounts for the majority of mis- or non- communication problems. A lack of internationally attended meetings is noticeable. When living in Europe, I noticed a lack of internationally attended meeting on this subject. In the United States, the Council for Office Products Energy Efficiency (COPEE), and the Consortium for Office Technology Energy Efficiency have meetings every few months. The Consortium has several international members, whom are invited to each meeting. Europe lacks this consolidated effort on keeping interested parties informed, despite the concerted effort on the part of the European Community's DGXVII, its committee for promoting office products energy efficiency. Seeing this lack of information readily available parities in Europe, I undertook to write about the main players in this field, in the hope that by providing some initial momentum, a stronger international consortium will form, that will ease the passage of information among interested parties.

Several countries have already started to explore the many options for improving the energy usage and efficiency of office equipment. Denmark, the United Kingdom, the Netherlands and France are at the beginning stages of involvement. Research projects are being performed in the area, most sponsored by the public sector. I will refer to this type of involvement as the involvement of the public sector in this area. While research may lead to policy making decisions, the actual decisions are not being made at this level. The European Community is sponsoring other research and examining policy options for improving the energy efficiency of office technology. The policy makers in Sweden, Switzerland and the United States have active programs promoting energy efficiency in office technology. The public sector of these countries is also involved in a variety of research projects. In particular, several aspects of one research project in the United States is presented in this thesis. Japan's policy makers have recently committed their involvement.

The role international standards play in energy-efficient office technology and what is being done with them will be discussed. After I started the revision process of the ASTM test procedure for copiers, and had begun writing procedures for fax machines and printers, I discovered that the Swiss government was also revising the standard, and developing new printer and fax procedures. They had not contacted the ASTM committee about their revision, so did not know that revision was already in process. I will present here an overview of my revision and new standards, and compare them to its standards.

II. Switzerland

A. Federal Government Programs

The Swiss government, through the Swiss Federal Office of Energy, has introduced a broad scope of regulations for the field of office equipment (Schmitz 1993). In 1990, it introduced the Energy Article into the federal constitution. This article requires the government to define principles for a rational use of energy and to issue regulations for the energy consumption of equipment. In 1991, the government issued the Federal Decree on the Use of Energy, which will be replaced in 1998 by an Energy Law. With this law, the federal government will issue regulations on standardized and comparable declarations of energy consumption of different equipment. It will define testing methods for energy consumption with an attempt to correlate the methods with international standards and recommendations. The sector involved will provide data and documents needed to control the effectiveness of the regulations. The Federal Regulation on the Use of Energy determines energy saving measures in detail.

The Message that accompanies the Federal Decree on the Use of Energy has two steps, but only the first involves office equipment at the moment. Here, target values for power usage in relevant groups of equipment are defined (Table 2.1). If these target values are not reached within a given time, mandatory standards may be issued in a second step. At the moment, standards are not up for discussion for office equipment. Target values are favored, due to the short lifetime of office equipment; they also would not influence trade restrictions, so are EC compatible. However, Japanese companies tend to react more quickly to regulations (Schmitz 1993). Therefore, minimum standards could be a powerful measure.

Table 2.1. Swiss Target Values for Office Equipment.

Device	Mode	Target Value (Watts)
Printer	Plug-in	0
	Standby	2
Facsimile	Standby	2
Copier	Plug-in	1
	Standby	27 + 3.23 x copier speed

The Federal Office of Energy attaches great importance to collaboration with manufacturers concerning the definition of target values. For office equipment, the target values will concentrate on standby energy losses in communication devices such as fax machines, data processing devices such as PCs and monitors, and output devices such as copiers and printers. Therefore, the types of equipment that consume a major part of Swiss electricity have to be identified. To do this, a database must be compiled which allows a projection of energy losses. Market leaders of the sector, the Federal Office of Energy, and independent experts, have formed a working group to propose necessary testing methods for target values. Based on these proposals, the Federal Office of Energy will prepare the corresponding appendix of the Federal Regulation on the Use of Energy which will be sent to the Swiss sector of industry for comments. Then, an adapted version of the appendix will be sent to the other sectors of the Swiss Government and to EC, EFTA and GATT countries for comments and notification. After comments are incorporated, the appendix will be signed by the Federal Council and implemented.

B. Energy Consumption Test Procedures

Development of test methods has already started. The Federal Office of Energy recommends the use of the American Standards for Testing and Materials (ASTM) test procedure titled "Determining Energy Consumption of Copier and Copier-Duplicating Equipment" (ASTM 1987), with minor revisions. It is currently preparing facsimile and printer test procedures (Ordinance, 1993), and have not yet recommended use of the procedures for printers and faxes under preparation by ASTM. They wanted to have completed, ready for use test procedures before the ASTM committee could make them available. When the ASTM procedures are available, the Federal Office may recommend the use of ASTM procedures. It has not scheduled a time when there will be a testing method for PCs. Comparisons between the fax and printer methods produced by ASTM and the Swiss Office of Energy will be discussed in detail below, in Section 6.

In preparing these test methods, the Federal Office of Energy worked closely with the economic sector, to clear up misunderstandings early, and to incorporate technical knowledge from the industry. It found that solutions to standby losses are known, the only barrier to the implementation of these solutions, is price.

C. Local Government Programs

Many laws have formed in the various cantons in Switzerland. For instance, in March 1989, Zurich imposed the Electricity Conservation Decree. In this decree, the electric utility for the city of Zurich (EWZ) is required to provide energy and electricity consulting services, help with building and installation improvements, provide tariff measures and conditions and restrictions for electricity supply (Hurlimann 1993). EWZ imposes an energy concept for all new buildings that use more than 110 kVA and for old buildings consuming more than 200 MWh/year. It asks for a status report of the concept every ten years. EWZ also assesses if the cooling of the building is really needed or if it could be avoided by a different building design or more efficient equipment.

Several projects regarding efficient use of energy in the office are in effect now with EWZ. For instance, it completed a project with vending machines so the machines now have standby operation during off periods. EWZ is currently working on a PC network server that switches off at night and on weekends. It is having a year-long exhibition including office equipment until the summer of 1994, entitled "On the Way to the Zero Electricity Office." This exhibition also includes energy-efficient heating, ventilation and air conditioning systems, and building design. It is targeting office workers, large buyers including banks which in some cases are performing studies of their own, and building maintenance workers by inviting them for special sessions and discussions focusing on the topic. It has had considerable press response to its activities. Also, it is supporting development of cost-effective methods of electricity consumption analysis in commercial buildings by reviewing possibilities for energy audits of office buildings. It is in the beginning stages of developing a data base for office equipment, and is trying to coordinate its activities internationally.

Switzerland does not have a strong market pull. On the other hand, Switzerland is often seen as a test market. It would like to see pressure brought to the other countries, a collaboration with other European countries, and the translation into English of decrees and regulations it performs.

D. Large Buyers and Industry Protocols

Several studies are being performed on various levels in Switzerland. One Swiss Bank, the Swiss Banking Corporation (SBC) has an environmental strategy that was implemented in 1991 (Knecht 1993). A task force was formed to analyze the environmental situation, evaluate opportunities and risks, and define key environmental activities. Key fields were targeted to find strategic options for the bank as a whole and proposals organized for the implementation of the strategy. SBC found that integration of ecological issues into company strategy was not a diversion of earning targets but rather a way of securing the bank's future by utilizing cost advantages and opening up new market opportunities.

The first step, an environmental audit, established priorities for office equipment and supplies. SBC also raised consciousness among the staff by integrating the ecological dimension into all aspects of company training.

SBC signed the UN "Banking and the Environment" declaration in preparation for the UNCED conference in Rio de Janeiro in 1992, and the "Business Charter for Sustainable Development" of the International Chamber of Commerce that aims to enforce the ecological awareness in Chamber companies.

Another study is one being performed for the Schweizerische Bangesellschaft (Swiss Banking Society, SBS) by Karl Heinz Becker in which a database is being formed of the energy consumption of various office equipment (Becker 1993). This will be used to help size the infrastructure for the SBS building, and possibly show office equipment with a higher energy efficiency.

E. Research Efforts to Promote Energy Efficiency in Office Technology

The main concern for the Energy Analysis Research Group at Eldgenossische Technische Hochschule Zurich (ETH) is to study the area of new information technology (NIT) (Aebischer 1992). It did an energy demand scenario for the "Communication Society" up to the year 2020, and is continuing the project by working on an analysis of the electricity consumption in the service sector in the city of Zurich. In this context it analyzed the energy use in a large computer center and showed in a power flow diagram the importance of indirect energy use.

ETH is also participating in the government project RAVEL, in which their support is being used to prepare a continued formation for professions in RAtional Use of ELectricity. ETH is collaborating with industry and retail stores to improve electricity use in Point Of Sale Network Systems, mainly by reducing standby losses and correct configurations of Un-interruptable Power Supplies (UPS). This project should give indications for power management in networks.

Also at ETH, there is a group at the Reliability Engineering Laboratory that is working on lifetime of equipment and power management (Miteff 1993). The Integrated System Laboratory is working on the development of a box for automatic power management for a particular manufacturer's workstations (Aebischer 1993).

III. Sweden

A. Federal Government Programs

By 2010 the Swedish government plans to phase out nuclear power plants completely, halt the expansion of the country's large hydroelectric system, minimize dependence on energy imports, and sustain anticipated 1.9%/year real economic growth (Mills 1991). Nuclear power provides half the power to Sweden now. The Swedish State Power Board, Vattenfall, outlines three stages to prepare the phase out. The first is to concentrate efforts on marketing measures, technical development and the procurement of new energy sources. The most intensive part of this phase lasts from the present until 1995, when stage two begins. During this phase, new power stations will be constructed; this will last until the beginning of 2000. Then, new electricity generation facilities will be commissioned and nuclear power plants will be shut down. This will last until 2010.

Different government procurement programs have already started in Sweden, with varying results. In the spring of 1992 a procurement program concerning printers took place, in which energy usage of different modes was to be provided by the vendor. However, in some cases, the vendor did not actually provide measured data, but instead used nameplate ratings, which has been proven to be as much as three times higher than measured energy usage (Norford et al 1990). This reiterates the need for standard test methods. There were two cases in which the printers were found to go down to a very low power state, thus supporting possibilities for energy efficiency in printing technology.

Other procurements and standards set by Sweden have been very successful. The standard recommendations for radiation from monitors set by MPR1 which was developed in 1990, is now internationally recognized. This standard recommends that certain types of electromagnetic radiation from monitors at Extra Low Frequencies (ELF) and Very Low Frequencies (VLF) should not exec certain values, given by Table 2.2. It can be hoped that manufacturers will also reduce the energy requirement of the equipment in order to reduce the radiation from monitors. Some organizations, such as Statskontoret that runs the central procurement programs on all equipment for all federal agencies, are including energy issues in office equipment as part of their procurement programs.

Table 2.2. MPR1990 recommendations for ELF and VLF radiation (ICL 1992).

Type of radiation	MPR1990 Maximum values
X-rays	100 nGy/h
Electrostatic potential	<±500 V
ELF	
Alternating electrical field	25 V/m at 0.5 m in front
Alternating magnetic field	250 nT at 0.5 m around or in front of screen
VLF	
Alternating electrical field	2.5 V/m at 0.5 m around or in front
Alternating magnetic field	25 nT at 0.5 m around screen

NUTEK, the National Board for Industrial and Technical Development, is very involved in promoting energy efficiency in office technology (NUTEK 1992). NUTEK's Department of Energy Efficiency is responsible for technology advancement and demonstration activities and for the market introduction of technology. The objective of the department is to demonstrate possibilities for improved efficiency through better products and work habits. More efficient products and services should be competitive with less efficient ones. It has opened dialog between manufacturers, researchers, and procurement offices, and has thus created a stronger market pull for energy-efficient office technology. This department also works closely with the Swedish Council for Building Research (BFR), the National Board of Consumer Policies and the National Housing Board.

NUTEK has been responsible for another successful program in Sweden, the program for self-adapting monitors (NUTEK 1993). In order to comply with this program, manufacturers have to produce monitors that meet NUTEK's specifications for having either an Automatic Standby Mode or an Automatic Power Off Mode. With Automatic Standby, the screen should black out in a specified time, and be readable with input from the keyboard or computer. The monitor automatically powers off within a specified time for Automatic Power Off, with no power being provided to the monitor. Again, the screen should be readable with input. These automatic functions must not have any significant impact on the lifetime of the monitor or interfere with the functions of the computer operating separately or within a network. However, when confronted with the lifetime issue, manufacturers have not been able to provide information on how they test for the lifetime issues. There has only been one study done thus far (Miteff 1991) on this issue, and few of the manufacturers seem to be aware of it.

Table 2.3. NUTEK's Monitor Program.

	Time to power down (minutes)	Maximum Power (Watts)	Time to refresh (seconds)	Automatically meets program
Auto Stand-by	5 - 60	30 % of operating, or 60 W	3	less than 25 W
Auto Off	60 +/- 10	5 W	ordinary refresh	

So far, six companies have been successful in manufacturing monitors that satisfy NUTEK's specifications; three have been actively marketing these products. It has received a lot of international attention. Other large monitor manufacturers have shown interest in NUTEK's programs, and seem ready to manufacture monitors that could comply. Since the target values specified by NUTEK are lower than those required by the Environmental Protection Agency's Energy Star Program (section 4), manufacturers which comply with the NUTEK program also automatically comply with the Energy Star Program. This has also led to discussion of changing the target values for the Energy Star Program for monitors.

NUTEK has also worked with the Video Electronics Standards Association (VESA) in the United States (section 4) on solutions to and test procedures for power management in monitors. Nothing has come of their collaboration thus far, however.

It also is interested in promoting automatic switches that act as power management devices by switching off equipment when it is not in use. These switches are being very well received now in Sweden. NUTEK is currently talking with two PC manufacturers about promoting its energy-efficient desktop machines that use the energy-efficient PCMCIA technology.

B. Energy Consumption Test Procedures

In addition to the program for monitors, NUTEK is also beginning to establish specifications for energy-efficient PCs, copiers and printers. A procurement program for copiers has also begun. This program separates copiers into four segments by speed: 500, 2000, 6000 and 20,000 copies per month. Manufacturers will be required to test their copiers using the American Society for Testing and Materials standard for the energy consumption of copiers, which is discussed in detail in Chapter 4. Initial target values for copiers in Sweden are being set.

C. Industry Protocols and Research Efforts to Promote Energy Efficiency in Office Technology

Swedish utilities, like US utilities, are emerging as promoters of energy efficiency, by providing users with information and financial incentives. For instance, Stockholm Energi has plans for a utility-operated retail store for energy-efficient equipment, and provides energy audits, among other things.

The Swedish Confederation of Professional Employees (TCO) launched an environmental labeling program of display units in 1992 (TCO). The program had several stages, the first of which covered power consumption of the unit and its effect on the working environment. The working environment includes improved humidity levels, and improved viewing of the monitor since as the monitor does not have a picture on the screen as often, the burn-in of the picture tube phosphor layer would be slowed down. The second stage focused on the environmental impact of the unit. A number of conditions apply before a manufacturer can be allowed to use a TCO Environmental label for its units. Among other things, the unit must meet TCO guidelines for electromagnetic radiation and Nutek's specification for auto power down monitors mentioned above. For TCO's radiation specifications, see Table 2.2 above. TCO's specifications are identical to the MPR1990 guidelines. Energy consumption during normal operation, standby and power-down states must be declared. Further stages of TCO labeling will include recycling of components, and declaration of heavy metals. SEMKO (Swedish Institute for Testing and Certification of Electrical Equipment) is responsible for doing the testing required for TCO certification.

IV. USA

A. Federal Government Programs

The General Services Administration (GSA), the procurement agency of the United States government, is the largest purchaser of office equipment in the world, and purchases ten percent of all office equipment sold in the United States. The government recognizes that energy savings in the office can save taxpayers money through the energy savings in government offices, decrease air pollution through decreased energy use, decrease the load for air conditioning and electrical systems, reduce fan noise and heat and increase the portability of the office, as well as decreasing the footprint of office equipment (GSA, 1993). The U.S. government purchases over $4 billion per year in office equipment, and spends some $125 million annually in electricity bills for use of office equipment (Harris, 1992). It is estimated that the savings potential in the US government is between 55 and 75 million dollars per year (Harris, 1993).

A market pull strategy for energy efficiency in office equipment was reinforced by several provisions in the 1992 Energy Policy Act (EPAct). Section 161 of the law directs the GSA to "include energy-efficient products in carrying out their procurement and supply functions." Also, the Department of Energy (DOE) is to work with industry on an energy testing and information program for office equipment, so purchasers can make informed decisions on energy use, costs and savings of energy-efficient office equipment. The responsibility for this program will be the industry's, but the DOE will monitor and evaluate the progress and effectiveness of the program. After three years, this evaluation may force the DOE to mandate programs.

The Environmental Protection Agency (EPA) has established the Energy Star labeling program as part of its program for pollution prevention and reduction of greenhouse gas emissions. This labeling program is a cooperative effort with manufacturers for personal computers, terminals and printers, requiring that PCs and monitors power-down to 30 W or less when not in active use. The following table outlines the EPA's program for printers, and compares it to some of the Swiss and Swedish programs.

Table 2.4. EPA Energy Star program for Printers.

Printer Speed (Pages per Minute)	Swiss or Swedish Target Values, Max. in Idle State (Watts)	EPA Default Time to Low-Power State (Minutes)	EPA Maximum Power in Idle State (Watts)
1 - 7	Swiss: 2	15	30
8 - 14	Swiss: 2	30	30
15+, color laser	Swiss: 2	60	45
Monitors, 1st stage	Swedish: 5		30
PCs			30

Manufacturers representing over 70% of the market for PCs and over 90 % of the market for laser printers have already joined this program. A number of computer and software allies have also joined. The EPA estimates that the Energy Star Program can save 50-75% for PCs, giving a savings of 30 dollars per unit per year. Laser printers could give a savings of 30-50%, or 20 dollars per unit per year. Assuming a 57 percent per unit projected energy savings and a 65 percent market penetration, this could save approximately 26 billion kilowatt-hours of electricity annually (U.S. State Department 1992), or using $.075/kWh, roughly two billion dollars in annual electricity bills. This is enough electricity to power three small states in the United States. The reduction due to

CO_2 is 20 million tonnes, which is the equivalent to 5 million automobiles (Johnson et al. 1992).

The EPA is currently negotiating with other countries to expand the Energy Star logo internationally. It has had several meetings with representatives from Japan, Sweden, France, Switzerland, Great Britain and the EC to discuss potential areas of collaboration. As can be seen from Table 2.4, there are different target levels set between the Swiss, Swedish and current EPA idle power targets values. The EPA chose these levels according to manufacturer specifications. However, since many monitor manufacturers are easily meeting the Swedish target values, it is likely the international target will be closer to the Swedish level. Further discussion of the other levels will have to be made before a decision is reached on the other levels. Establishing an internationally recognized program is vitally important for its success, since it would avoid confusion for manufacturers and procurers that an assortment of differing labeling programs would bring. A higher impact on the market could be attained by working together towards the same goal, rather than working in different and possibly mutually exclusive directions.

A 1993 executive order, issued by the President of the United States, states that all federal agencies must purchase energy-efficient office equipment that meets the EPA's Energy Star Program. Energy-efficient office equipment must also be included in the "Greening of the White House, " a program in which the energy efficiency of the White House will be improved.

The executive order will ensure GSA's support of the purchase of Energy Star equipment. Included in this support is education of users and procurers through training sessions on procurement, adaptation of energy-saving behavior, and education in energy-efficient systems designs and operation. It also will keep track of the performance of Energy Star equipment. There are several issues not covered by GSA guidelines, but that are being discussed with users and vendors, and will be a part of future guidelines. These include telecommuting, wireless LANs, and sound disposal or recycling of equipment.

Other government programs include the Office of Federal Procurement Policy Letter 92-4, November 7, 1992, which requires Federal agencies and departments to implement "cost effective procurement preference programs favoring the purchase and use of environmentally sound, energy-efficient products and services". With the Federal Acquisitions Regulation (FAR) SubPart 23.2 Energy Conservation, agencies must apply energy conservation and efficiency criteria to acquisitions "whenever the results would be meaningful, practical, and consistent with agency programs and needs." On 21 April, 1993, Clinton called for energy-efficient initiatives for federal energy management and voluntary programs to reduce business energy costs during his Earth Day Address.

B. Energy Consumption Test Procedures

The Computer and Business Equipment Manufacturers' Association (CBEMA) has been active in developing legislative provisions, industry-based energy testing and information programs for the EPAct. It has formed the Council for Office Products Energy Efficiency (COPEE), to advise CBEMA on the establishment of the programs. Members of COPEE include many of the members of the informal consortium described in the next section. COPPEE's aim is to support test methods that would give accurate accounts of office equipment. It is considering the use of target values for equipment electrical power, but it favors using methods to judge the equipment based on technology options and power consumption. The tests may include two or more ratings, average and suspend power, a level measured when the machine is in a power management mode (consuming less power than when idle and ready for immediate use) but the information provided from these tests may only provide one or two values. The goal would be to move manufacturers towards higher goals of energy efficiency, not limit technological development or encourage the purchase of inferior equipment. It is also working with government agencies and utilities on programs already mentioned.

The Video Electronics Standards Association (VESA) has developed a communications protocol for host-based VDT power management which addresses "sleep" modes of terminals based on signals from the computer host. The Imaging Committee of the American Society for Testing and Materials (ASTM) has updated its 1987 version of a test method for energy use of photocopiers and duplicating equipment, which will be published in the next book of standards, available in August. It also has prepared first drafts of similar methods for printers and fax machines. A test procedure for computers and monitors is also being prepared at the Massachusetts Institute of Technology (MIT) (Chapter 4).

C. Industry Protocols and Research Efforts to Promote Energy Efficiency in Office Technology

Several major corporate and government purchasers of office equipment in the United States and Canada, including the GSA and Canadian utility Ontario Hydro, have created an informal consortium with industry, electric utilities, state and federal energy research agencies and non profit groups. The group's aim is to improve the energy efficiency of office equipment, and to quickly bring to the market new types of equipment. It is working to bring together the industry and customers to create a market pull (Harris 1993). It has sponsored workshops and established information programs for purchasers. Also, it has supported data collection on office equipment energy use, and researched further opportunities to improve energy performance. Consolidated Edison, an electric utility company in the state of New York, sponsored a Buyers Fair and Trade Show in 1993. Further workshops, buyers fairs and trade shows are also planned by members of the consortium.

Among other things, the consortium envisions a new approach for the government; helping to create and strengthen the market rather than replace market mechanisms with regulations. In order to do this, industry-wide international standard methods for testing and rating relative energy performance for each type of equipment need to be produced, then followed by programs to assure that the resultant data are accurate and made available to interested parties. A Buyer's Guide has been developed by ACEEE (Ledbetter, Smith 1993) that will help customers choose energy-efficient features. A Technical Assessment has been prepared by MIT (Chapter 3) that should provide a technical basis for more buyers guides and areas for related research. Another Buyer's Guide is forthcoming from the Ministry of Energy, Mines and Resources in Canada. Ontario Hydro of Canada has started to define energy efficiency test requirements for photocopiers and fax machines into its procurement criteria (Kurtz 1993).

V. Denmark, the United Kingdom, France, the Netherlands, the EC and Japan

A. Denmark

1. Federal Government Programs

In Denmark the energy administration some years ago implemented a program called "Control the Energy" (Rebsdorf 1993). The program included education for energy use in buildings of procurement officers and other people who would benefit in the public and private sector. It will decide on the best approach to better energy efficiency in the buildings. The Minister of Energy and the Energy Administration initiated the production of a booklet on energy efficiency in the office.

2. Industry Protocols and Research Efforts to Promote Energy Efficiency in Office Technology

The Research Association of Danish Electric Utilities (DEFU) was responsible for the education of the energy advisors. It also participated in the production of the booklet mentioned above, in cooperation with the Danish Trade Union, which focuses mainly on the procurement of office equipment, and includes information on how to reduce the energy consumption of existing office equipment. The data included in the booklet are from measurements made by DEFU. A product recommended by DEFU is currently on the market now, that reduces the energy consumption of monitors, meeting NUTEK's standards for monitors.

DEFU will also be responsible for a study proposed by the Directorate-General for Energy in Denmark, on preparing a database for office equipment. It is trying to coordinate this effort internationally, so as to avoid duplication of effort. It will work on a translation of its buyer's guide and an evaluation of an open and effective European office equipment database (Jensen 1993).

3. Energy Consumption Test Procedures

Representatives from DEFU are currently examining the ASTM test procedures for use in collecting data for the European database. They are also communicating with other research groups on existing databases for office equipment.

B. Great Britain

Over the past few years, the British Research Establishment (BRE) of the United Kingdom has been carrying out a detailed study on the energy consumed in various office buildings. From this study BRE will determine a means of minimizing the consumption. This work has been performed in close liaison with the Building Service Research and Information Association (BSRIA). A detailed presentation of this report is in the EC task force report mentioned below (Hill 1993).

C. France

In France, a group at the University of Bordeaux has been working since 1987 with the support from Agence de l'Environment et de la Maitrise de l'Energie (Ademe), through its cooperation in the European Community's SAVE program, established in October of 1991. Ademe is sponsoring the group's activities in evaluating possible energy-efficient actions for office technology. This group is interested in measurements of office equipment power usage and power quality, particularly harmonic distortion. The group is involved in identifying different standby modes that have been previously recommended. It is also looking at recycling options for end of life office equipment. Ademe has signed an agreement with EDF, the French utility company, and is now trying to coordinate efforts with EDF in the area of office equipment (Lebot 1993).

D. The Netherlands

The Netherlands has several organizations that are looking at energy consumption of office equipment. Groups in the Netherlands depend more on suggestions from the government than on policy making decisions. For instance, Digital Equipment Corporation in the Netherlands has put to use Environmental Management Systems, British Standard number BS 7750: 1992. This is a structured management system which helps an organization meet legislative and policy requirements. It specifies required elements of a system for the development, implementation and maintenance of environmental management systems aimed at ensuring compliance with policies and objectives of an organization. It can be applied to all types and sizes of organizations, and is partially intended to support certification schemes. The Dutch government has suggested that all large organizations in the Netherlands comply with this standard by 1995. Digital Equipment Corporation is also highly involved in the reuse and recycling of end of life office equipment to reduce the growing costs of waste disposal. It is concentrating its efforts on recycling because it foresees future regulations mandating recycling end of use office products. By initiating efforts now, it won't be pressed to do so in a later stage. The Netherlands is also beginning to look at the possibility of instigating programs similar to those started by NUTEK in Sweden, starting with power-down monitors, and moving to other forms of office equipment such as copiers and printers.

E. The European Community

The EC has formed a task force called Energy-Efficient Office Technologies in Europe, which will be finished this year. The British and French projects mentioned above will included in this report. Also, contributions from Finland and Portugal will emphasize indirect energy costs such as air conditioning costs and costs due to poor power quality. The goals of this task force are to assess the actual load and power consumption due to office equipment, and the conservation potential due to the reduction of this load. It also aims to determine how the EC can define a market pull strategy from environment regulations of governments, defined standards, or manufacturer voluntary programs and incentives for users. A workshop on "Energy Environment Approach to Computerized Systems: From Design to Utilization," was held in 1993 for manufacturers, users and researchers (Roturier 1993).

F. Japan

The Japan Electronic Industry Development Association (JEIDA) is working with the Ministry of International Trade and Industry (MITI) to broaden the law passed in 1979 on the Rational Use of Energy. This law, initially aimed at improving energy efficiency of factories, building and industrial products, has draft revision to include the improvement of computing performance per watt of energy consumed, and to set a new standard by 2000. A committee set up in 1992 by JEIDA is looking at standards for energy efficiency in computers. It is modeling the standard on the power consumption of the equipment per composite theoretical performance, then classified into ranks according to this comparison. It has also started discussions with the European Community, and related groups in the United States, such as the Consortium and the EPA. It will take other programs into consideration before determining its final energy efficiency standards. It is very concerned about correlating their activities internationally.

Another committee formed by JEIDA is working on voluntary programs for energy-efficient personal computers, printers and displays, possibly in co-operation with the EPA and Europe. They are determined to develop this program in harmony with the United States and Europe, particularly following targeted products, power levels, logo and testing methods. It plans to publish its guidelines in April 1994.

VI. Test Methods and Standards

Standard methods of evaluating energy consumption of office equipment are very important in order to make valid comparisons between machines. These methods need to be internationally recognized to avoid conflicts in data. This will avoid incompatible data results, as was the case with the results which manufacturers provided for the Swedish procurement of printers. Confusion will result if manufacturers are asked to report data to different procurement programs that use different procedures, which could be the case if the Energy Office in Switzerland uses procedures differing than the more widely accepted, and superior ASTM procedures. Its use of its own test methods for fax machines and printers will produce results very different from those reported with the ASTM procedures.

The differences between the fax and printer methods produced by ASTM and the Energy Office are considerable. Both are currently in draft form and may change. The most current versions mainly show differences in results presented and in ways the tests for the operating modes are performed. A comparison follows; an in depth analysis of the ASTM procedures will be performed in Chapter 4. In Chapter 5, I will examine the operating profiles of the machines, and compare them to the test methods.

The Swiss methods test for average power usage in operating and standby modes for both procedures, and plug-in for the printer procedure. It also tests for average daily energy consumption. The ASTM method tests in operating, energy saver and standby modes for both methods, and in warm-up and plug-in mode for the printer method. The reported results for the ASTM method are the average monthly energy consumption, and the average energy consumption per page.

When testing these different modes, the ASTM method tests for an hour in each mode. Operating energy is tested with the use a job matrix that allows for differences in nominal monthly volumes of the machine, to determine the number of jobs, the number of pages and the job interval for the imaging process. The Swiss method for calculating the average operating power has one estimated job interval that is used for all machines. Another estimated job interval is used to calculate the daily energy consumption. The values attained through the method are multiplied by an assumed number of hours of usage; however, in the current Swiss procedure, not all hours of the day are accounted for. The ASTM procedure also estimates a number of hours of usage over a month period, which accounts for weekday usage, as the Swiss procedure does, but also accounts for weekend usage. Also included in the results attained through the ASTM method are values for the energy saver modes. The hours of use are dependent on the amount of time the machine takes to go into and come out of the energy saver modes. The two Swiss procedures do not include energy saver modes.

The Swiss procedure also does not state specifically how the machines are to be tested. The ASTM procedure specifies the way a fax machine is connected to another identical test machine, for example, in testing fax machine energy consumption. It specifies the use of certain devices in testing, to cut down on uncertainties due to timing; in the case mentioned, different telephone services and length of telephone lines effect the amount of time required to transmit and receive faxes. The Swiss procedure specifies resolution and other types of configuration, while the ASTM procedure requires the user to test for each type of configuration.

The ASTM committee consists of manufacturers, users and general interest groups, with a percentage limit set for each group. It has a broad representation from industry, in areas including toner, ink and paper as well as machinery. Each procedure must be first approved by a subcommittee before moving onto the main committee ballot. After approval, the procedure is published in its annual book of standards. The ASTM body is non-biased, with each procedure following a certain method, so each is similar and therefor easier to understand.

The most recent version for the ASTM method for energy consumption for copiers is in its final stages of revision. New versions for printers and fax machines are under way, which are very similar to the copier procedure (Chapter 4). The test should be used as a tool for comparison, not to give accurate energy consumption predictions for individual machines. Certain assumptions are made based on hours per day of use. Also, measurements are made based on manufacturer's recommended volume, not on actual volume of individual copiers. Through revisions of these assumptions, the method can be adapted to give accurate predictions.

NUTEK of Sweden has convinced manufacturers to test copiers using ASTM methods as they are approved by the ASTM committee. The details of this policy decision have not yet been worked out. It will use the ASTM method for copiers, and will use the printer and fax methods as soon as they are published. Once there are standard methods for collecting data, manufacturers will be able to test their machines accurately for energy consumption, thus giving many of the procurement programs mentioned above a greater base for comparison. Focus on these methods is taking priority by the ASTM committee and a group from MIT who are working on them (Chapter 4).

A computer test method is the only method so far that has received relatively little attention, primarily because of the difficulties associated with such a test, which I will discuss in more detail in Chapter 4. Several suggestions have been made for the development of a test procedure. A representative from IBM suggested that the method be based on performance and productivity as well as energy consumption. However, this method seems to be extremely difficult, since a definition must first be made of the two factors. Also suggested was one based on the ASTM method, with a certain job the tester would perform to test the operating mode. Tests for one hour each could also be made in a ready mode (similar to a copier's standby mode), standby and suspend modes (power management modes), and warm-up and plug-in modes. I have developed this method, and included it in Chapter 4.

VII. Conclusion

As electric loads rise around the world, decision makers are forced to look for new energy resources. In the mid-1980s, scientists began to look at a new form of conservation potential, that of energy efficiency in office technology (Norford et al 1990). Now, as environmental concern widens, the subject of increasing efficiency in office technology is attaining greater attention.

Users cannot be expected to opt for energy efficiency on their own. Often, the words energy and power are associated with performance, not with electricity usage. Thus when phrases such as less energy and lower power are employed, users may choose a less energy-efficient model, since they may mis-interpret the meaning of these phrases. User awareness of this new conservation potential needs to be broadened. Government involvement could speed this process along, by providing an initial market, and advertise the desirability of such products through press announcements of various programs. In turn, the manufacturers could concentrate efforts on advertising their energy-efficient products in a way that would attract more buyers.

Table 2.5. Summary of Level of Involvement in Europe and the United States.

Country	Federal Government	Test Procedure/ Target Values	Industry/ End Users/ Utilities	International Cooperation
United States	*****	*****	*****	*****
Switzerland	*****	*****	*****	***
Sweden	*****	*****	*****	*****
Denmark	***	**		**
France	*	*		*
Great Britain			*	*
The Netherlands			**	
The European Community	n/a	*	****	****
Japan	*****	***	*****	*****

As can be seen from Table 2.5, policy makers of the government and electric utilities in the United States and two European Free Trade countries, Switzerland and Sweden are strongly supportive of energy efficiency in office technology. Japan's policy makers are also involved in this area. The stars symbolize, from the evidence obtained in the preceding sections, the extent of involvement of each country.

With the help of government procurement programs and the focus of utilities and research groups on this area, manufacturers are increasingly concentrating development efforts on more efficient products without inhibiting technological innovation. User awareness has been increased through such programs, and with the help of purchasing guidelines and criteria being developed, and with various test methods. Thus, manufacturers are finding a strong response in these countries to marketing efficient models by stressing increased efficiency and environmental awareness.

It is important for these criteria to be followed in the European Economic Community. In Denmark, the Netherlands, England and France, it is the public agencies that are involved, not the policy makers. For instance, if the French government developed policies similar to those announced by U. S. President Clinton, enforcing the procurement of Energy Star computers, monitors and printers, manufacturers who have a large selling base in France would be forced to concentrate on energy-efficient issues in their equipment. Alternately, if the French utility supported research in this area, more attention would be paid to this issue in France, users would become more aware of the issues in this area and again, manufacturers would be forced concentrate on energy efficiency. Besides legislative governments, utilities have access to a much wider base of large buyers than any other groups. By holding workshops, including buyers guides in mailings, and having demonstration offices, they are in an easier position for convincing users to buy energy-efficient equipment. In order to push users and manufacturers towards using and producing more efficient models, policy makers need to become involved. Also, purchasing guidelines and test methods need to be international, to avoid confusion and to reinforce their use with manufacturers.

Chapter 3: Technology Review of Electronic Office Equipment

I. Introduction

The electrical power (inherent in machine operation) and energy (a convolution of power in all operating modes and time in each mode) used by office equipment has become a topic of interest to a worldwide community of equipment users and energy analysts. No longer an issue solely for product designers, who are faced with constraints posed by heat dissipation from equipment packaging, or building owners faced with limited electricity distribution systems, energy consumption first entered the literature of the energy conservation community in the late 1980's. Norford et al. (1988, 1990) measured electrical power drawn by a number of machines and noted that measurements were typically considerably less than 50 percent of nameplate ratings. They also briefly reviewed a number of technologies, for both computers and imaging devices, that offered improved energy efficiency and assessed the aggregate impact of these technologies within the United States. Michaels et al. (1990), DeLaHunt (1990) and Pratt et al. (1990) examined the energy use of office equipment in the service territories of specific electric utilities, working from utility load survey data. Lovins and Heede (1990) published a definitive review of office equipment energy usage, including in-depth information about imaging technologies. Recently, Piette et al. (1992) completed a detailed assessment of the office equipment energy usage for a California utility.

The subject has now moved to a position of some visibility to the computer trade press (Reinhardt et al. 1992, Nadel 1993), equipment manufacturers, and equipment purchasers. Some equipment purchasers and electric utilities and government agencies in the U.S. and Sweden are now encouraging manufacturers to develop more efficient products without inhibiting technological innovation. These efforts are in the form of "meet or beat" electrical power limits that currently apply to computers, displays and printers. Purchasing guidelines and criteria are being prepared by the U.S. Government Service Agency (GSA), responsible for federal government procurement, as well as other state and foreign government agencies.

Computers and peripherals continue to grow in performance and, often, their demand for electrical power. However, key technologies, which are currently on the market or are about to be introduced, promise improvements in operating energy and especially in reduced power when equipment is idle. In this report we will review power requirements and technology trends for computers, displays, copiers, printers and faxes, with the goal of identifying minimal power draw and energy consumption, particularly under standby conditions. We will also survey future trends, which point toward increasingly powerful computers, more ubiquitous computing, and larger displays.

II. Computers

Energy used per microcomputer has typically grown with computing power. Computers generally operate at nearly constant power levels for individual machines. These power levels tend to increase with more powerful microprocessors, more memory and more disk storage. Particularly for desktop computers, there have not been any perceived need or industry response to address the electrical power usage when the computer is not in active use. However, there are reasons to predict some degree of decoupling between energy use (more than peak electrical power requirements) and computing power. Low-power portable computers with power management, automatic power switching of computers and displays after user-specified periods of computer inactivity, and industry's willingness to produce products that meet power-reduction targets established by the U.S. Environmental Protection Agency (EPA) all augur a potentially lower power future.

Our review of computers will highlight the growth in computer power levels, near-term and future trends, including EPA's program, the types of power management used in portable computers, and the power-management potential for desktop computers.

A. Microcomputers

1. Technologies

The power required solely by a microprocessor, or central processing unit (CPU) can be expressed as the product of the processing speed, the number of transistors being switched, and the energy required to switch each transistor, which in turn varies with the capacitance and the square of the voltage. Capacitance scales with transistor size. The number of transistors in a CPU has increased faster than the transistor size has decreased, as indicated in the growing dimensions of CPUs. The Intel 8086 had 29,000 transistors with a minimum feature size of 3.0 micron while the new Pentium CPU has 3.1 million transistors and a feature size of 0.8 micron. The 8086 CPU operated at less than 5 MHz while the Pentium runs at 66 MHz (Halfhill 1993). Maximum CPU power has increased, with the Pentium requiring 13 Watts when operating at full speed and at 5 Volts, and the DEC Alpha CPU, running at 200 MHz and 3.3 Volts, is reported to draw 30 Watts. These CPUs thus draw more than some complete laptop computers that employ less capable CPUs operating at lower speeds.

New Pentium-based workstations and servers are on the market and many computers now sold with Intel's 80486 CPU are reported to be capable of accepting the Pentium as a future upgrade. The Pentium runs hot and may require a large heat sink, a chip-mounted cooling fan, or additional cooling within the computer case (Seymour 1993); the last two options would require a small amount of additional fan power.

The increase in electrical power as CPUs are improved has supported an even larger increase in computational power, expressed in millions of instructions completed in each second (MIPS). Computational power also scales with processing speed. Each instruction requires that a number of transistors be switched. The ratio of MIPS and power therefore varies with the inverse of the energy required to switch a transistor. The ratio for the Pentium is 8.6 MIPS/Watt, about an order of magnitude higher than the norm for CPUs in the late 1980s and perhaps an order of magnitude lower than what is anticipated by 1995.

Operating speed can be tuned to the computer's activities. Numerical processing requires maximum speed but word processing is typically limited by slow typing rates of a few keystrokes per second. Alford (1992) notes that Intel and AMD both have produced 80386 processors that are fully static CMOS devices which can operate at clock speeds as low as 0 MHz. Both manufacturers offer 3.3 V versions of their processors in addition to the standard 5 Volt product. A newly introduced, power-managed desktop computer uses a 3.3 V 486 CPU. The Pentium processor will be offered in a 3.3 Volt version; this change alone would boost the efficiency to nearly 20 MIPS/Watt. The DEC Alpha, capable of 400 MIPS, has an efficiency of 13 MIPS/Watt. These machines use from one to six CMOS CPUs in lieu of the less energy-efficient emitter coupled logic (ECL) used in previous, water-cooled machines (Zorpette 1993). Alford notes that 3.3 V memory chips are also being introduced and that disk drives and other subsystems will soon follow.

By 1994, complete 3.3 V chip sets should be available to designers of office equipment. Some experts forecast a 10-year lifetime for 3.3 V operation but note that 2.5 and 1.8 V designs are on the way and that specifications have been developed for 1.5 and 1.0 V chips (IEEE Spectrum 1992 and 1993). Processor systems running on 2.0 V are now available on some PCMCIA cards. The impetus for lower voltage is two-fold: longer battery life or reduced battery size and weight in portable computers and more reliable operation of chips, particularly dynamic RAM, as the size of transistors on the chips continues to shrink. Currently available 4 Mbit DRAM is powered at 5 Volts, next-generation 16 Mbit DRAM is being developed to run at 3.3 V, and future 64 Mbit DRAM may drive technology toward 2.5 V. Transistors have been manufactured at sizes so small as to serve as the building blocks for 4 Gbit DRAM, three generations in the future from 64 Mbit memory chips and five generations from today's memory chips (Self 1993).

Lower voltage offers important power reduction but energy analysts should remember that the trend to lower voltages is simply a necessary response to higher transistor densities on chips. Failure to reduce chip voltages results in chip failures and excessive chip temperatures. While the benefits appear dramatic at the time when a lower-voltage product is announced, a long-term view indicates that it simply balances some of the increases in transistor count and chip operating speed.

Trade-journal speculation about Intel's next CPU, the P6 suggests that this chip might be introduced in 1995 and will execute 200 MIPS while running at 66-132 MHz (Feibus 1993). The processing power is equal to the Alpha, suggesting that the electrical power will be comparable. While new chips are introduced into high-end workstations and servers, they quickly become more commonly applied.

Some workstations or servers are capable of using more than one CPU. A leading manufacturer of workstations based on reduced-instruction-set computing (RISC) architecture markets one model that can use as many as four of the chips for parallel processing (Comerford 1993). Another manufacturer has announced a server that uses as many as eight Pentium CPUs.

2. Power Levels

Computer power measurements have been reported by Norford et. al (1990) and others. Huser (1991) has a particularly comprehensive set of data for most types of office equipment; these data are the basis for Figure 3.1. His data show that "late model" computers use more power, on average, than their predecessors. Computers with the Intel 80286 microprocessor required, an average of 33 W, with a 20 % variation; a sample of computers with the 80386 microprocessor needed 46 W, with a 31 % variation; and a sample of 80486-based machines needed a significantly larger 79 W, with a 36 % variation. Data exclude displays. Similar trends are apparent for the Motorola family of 68000 microprocessors. Huser reported an average operating power of 16 W for a sample of seven portable computers that include displays, about 10-15% of a comparable desktop computer with a larger CRT display.

For most purchasers, a choice in favor of energy efficiency must not result in a decrease in a computer's capabilities. Within a given class, there were several computers with double the memory or speed, that used only half of the operating power. Also, an upgrade to a better processor does not always increase the computer's power usage. While the average power usage of machines increased with greater capabilities, the least energy intensive 80486 computer used much less power than the most energy intensive 80386 machine. The particular architecture of the computer is a major cause of the wide differences in power consumption. More capable computers may have larger data-storage capabilities; more peripheral devices, including input-output ports; and wide pathways, or busses, for data transfer within the computer. These machines are more likely to be used as servers to multiple clients rather than be dedicated to a single user. Computers purchased for numerical work will also include a processor for floating-point mathematical operations.

Of note in Figure 3.1 is the line at 30 W, the maximum value for the low-power suspend mode for computers (not including displays) participating in EPA's Energy Star program. This program, announced in June 1992, encourages manufacturers to incorporate power management into desktop computers. Standard terminology is helpful in reviewing power management in computers and displays and the following definitions are used by the Video Electronics Standards Association (VESA) in its Display Power Management guidelines, which are compatible with the Microsoft/Intel Advanced Power Management Protocol for computer power management (Ryan and Anwyl 1993):

Ready (On)	full power operation
Standby	instant power recovery, minimal power savings
Suspend	longer recovery time, maximum power savings
Off	equipment non-operational

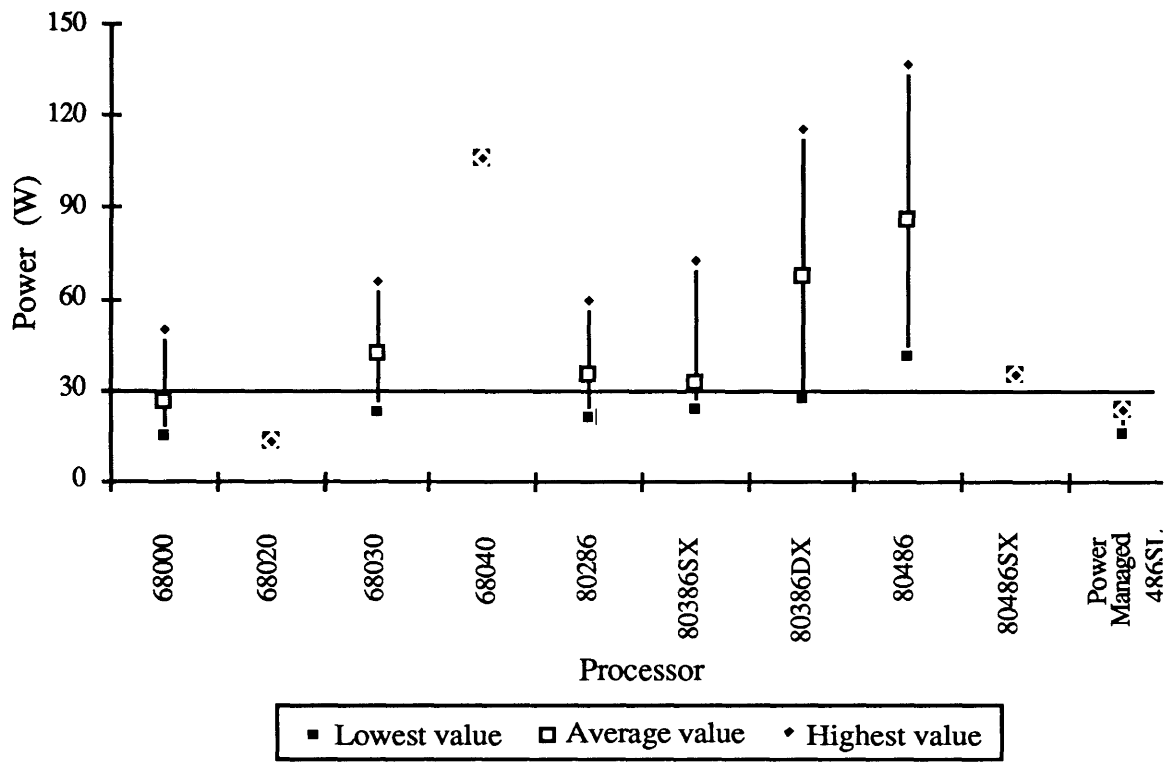

Figure 3.1. Low, High and Average Power Consumption for Desktop Computers.

Note: *For the power-managed 486SL computer, the two power levels apply to operating and standby modes.*

In June 1993, EPA recognized those computers that have met its target of 30 Watts maximum power in a suspend condition. EPA expects manufacturers to have a number of products on the market before June, although they will not receive the Energy Star logo until that date. Many desktop computers already meet or come close to this value in an *operating* mode. There were a total of 14 computers that fell below that cut-off point already, out of a total of 52 samples, and half of the 14 use the relatively recent vintage 80386 family of processors. Notice as shown by the graph above that the average value for a 386SX is only a little above 30 W, and all machines (except the 68040, of which there is only one data point) had at least one machine near 30 W. One computer, featuring a 486SL CPU with power-management features, is produced by a company participating in EPA's program. This machine reportedly uses about 24 W in operation and only 16 W in standby, not including the display. While the EPA target encourages participation from a number of manufacturers, but does not substantially push the state-of-the-art, leaving full achievement of potentially realizable savings to manufacturers' initiative and better peak demand and energy performance targets in the future.

B. Data Storage

1. Hard disk drives

Hard-disk storage density continues to grow, offering more storage for a given disk size and disk-drive motor. Many personal computer users are accustomed to disk drives that can store on the order of 100 MB. Storage densities an order of magnitude larger are now possible. One manufacturer of hard disks produces a 5.25" drive that can store as much as 3.7 Gb of data while a 3.5" drive goes as high as 1.4 Gb (Hitachi Technology 1992).

So-called subnotebook computers have driven the industry to produce smaller disk drives with higher storage densities. Disk drives produced by competing manufacturers have shrunk to 2.5", 1.8" and even 1.3." (Comerford 1993). At this size, the density of a hard disk is reported to compete favorably with that of flash RAM, a solid-state data storage medium.

For a given size, power is not sensitive to storage density. One manufacturer lists the products shown in Table 3.1 (Western Digital 1993). The smallest, low-capacity drive has a vanishingly low suspend power. The spinup power, which influences the size of the computer's power supply, is also low, varying approximately with the square of the diameter, as would be expected from a calculation of moment of inertia.

Table 3.1. Power requirements for hard-disk drives.

Size (In.)	3.5	3.5	2.5	1.8
Capacity (MB)	171/341	213/425	131/171	43
Powers (W)				
Read/write	3.1	3.2	1.9	1.75
Idle			0.90	0.70
Standby	0.50	0.42	0.18	0.20
Suspend	0.40	0.42	0.15	0.005
Spinup	15.0	15.0	3.5	3.0

Another manufacturer (HP 1993) specifies 7.0 W for spin-up and 5.0 W for operation of a 450 MB hard disk drive. The operating power is similar to that specified in Table 3.1, reinforcing the power figures presented there. This same manufacturer calls for 3.0 W for a CD-ROM drive.

2. New Storage Technologies

Researchers at AT&T's Bell Laboratories have developed a new technique that can store information at densities 100 times higher than today's magneto-optical drives (Bell 1993). In conventional magneto-optical drives, light is focused to heat a spot on the surface of the storage medium. The minimum size of the spot is limited by diffraction of the light. Near-field scanning optical microscopy (NSOM) uses a tapered optical fiber to funnel a laser light source to a size smaller than the wavelength of the light and holds the source closer than the light's wavelength from the magneto-optical material by means of a shear-force regulator that measures aerodynamic drag between the surface and the source. By using sub-wavelength distances, NSOM circumvents the ordinary diffraction limits. Storage densities are nearly 7 Gb/cm^2.

3. PCMCIA

The standard interface format developed for solid-state memory cards by the PC Memory Card International Association (PCMCIA) is being used for many purposes in addition to memory: miniature hard disks, mounted on a card, co-processors and communications devices. PCMCIA-compatible products developed for portable computers and stringent constraints on electrical power can be readily used in desktop computers as well, as is the case with the power-managed desktop computer recently introduced by IBM. The introduction of field programmable gate arrays, a user programmable device, allows the user to implement custom design, providing flexibility to include the necessary functionality required for design. PCMCIA Serial I/O cards exists, to provide serial data transfer.

The memory cards generally have a memory capacity varying from 1 Mb to 80 Mb, depending on whether the card uses solid state storage (flash memory) or rotating storage. Subminiature disk drives include single platter 32 and 42 Mbyte 1.8" drives and, in the future, 64 Mbyte double platter 1.8" drives will probably be available as a new proposed standard. Hewlett Packard recently demonstrated a 1.3" hard disk drive. While some predict that the smaller, 1.8" drives will eventually replace the flash memory due to higher storage capacity and less cost, it is more likely that they will co-exist. Flash memory's highest capacity currently available is 40 Mbytes (Memory Card 1992). Hard drives generally offer two to four time the capacity of flash memory, but flash devices offer lower power consumption figures. Flash RAM requires 0.13-0.35 W for read/write operations, compared to 1.75 W for the 1.8" hard disk noted in Table 3.1 and 0.002 W in suspend mode, compared with 0.005 W for the hard disk (Legg 1993). The suspend power for both technologies are vanishingly small. Flash RAM's advantage in lower operating power and the power penalty associated with spinning up a disk are being addressed by sub-miniature drive manufacturers by designing power management software into the drives. The smaller drives include capabilities of writing data directly into a solid-state buffer, so the disk will not spin up until the buffer is full. These buffers are up to 128 kbytes, which are four times greater than most 2.5" drive buffers (Memory Card 1992b).

At this point, flash memory is most useful for personal digital assistants (PDAs). Typically, PDAs will be downloaded directly to a desktop daily and thus will require less storage than the subminiature drives offer, with power saving advantages. Transfer of information from the mobile equipment to desktop equipment is much easier if the desktop has PCMCIA capabilities as well. Desktop computers using PCMCIA cards for data storage can readily increase storage capacity by adding cards to available slots. Some desktops already include PCMCIA slots, and the number of such computers is expected to increase in the near future.

C. Power management in portable computers

Except for a handful of new machines with power management, desktop computers have been manufactured with no design goal to reduce power and have required a larger flow of electricity than portable models, both when operating and while idle. As now established by the power-managed desktop computers, these electrical power differences are narrowing. It is worthwhile to examine portable computers in sufficient detail to establish the technical potential of power reduction and energy savings in desktop equipment.

The main difference between a laptop and a desktop is the bus. The laptop typically comes as a complete package, with little opportunity for add-ons, and power management is more easily implemented by the manufacturer. If power to the bus in a desktop computer is switched off, a peripheral device plugged into the bus may crash or may require special initialization when power is restored. One common bus first employed in 80286 computers is not designed to solve these problems, but it is simple, inexpensive and is widely used. Designing a new bus for desktop computers is possible but costly.

Table 3.2 The potential for power management of hard disk drives.

State	Controlled Components	Power (Watts)	Resume time (seconds)
	None	1.2 (3.5 to speed up)	0.0
Standby	Electronics	0.9	0.1
Suspend	Disk drive, electronics	0.06	3.0

Power management in computers requires a combination of hardware and software. Logic must recognize inactivity and shut down unnecessary components of the computer and the components themselves must be capable of receiving and responding to a power-management control signal. For fixed-disk drives, both the electronics and the mechanical drive can be shut down, as shown in Table 3.2 The electronics account for about 25 percent of the total, and can be powered up in a near instantaneous 0.1 second. The remaining 75 percent of the power is required by the drive itself, which can be cut back to the extent that residual power is only 5 percent of the total operating power. The penalty for a 95 percent power reduction is the relatively slow recovery time that may be as long as 3.0 seconds.

Power management affects virtually the entire machine, including the display, peripheral ports, memory and the CPU. Typically, software provided with the computer permits users to set the time-out period for displays and the disk drive and to reduce the speed of the CPU. Most portable computers have one or two packaged power-management procedures which take several actions, after a period of inactivity that can often be adjusted by the user. Power management modes include full-on, standby, suspend and off. Intel defines the "instant" response from the standby state as being less than five seconds. In addition, Intel identifies a mode called "power managed" which exists between the full-on and standby modes. This state, used in portable computers, offers device-specific power management, turning off unused components while others are fully active. It is of particular interest in a networked environment, where a computer's video could be powered down while the computer communicates with the network during night hours.

<u>Standby mode</u>: Disk drive is slowed down or turned off, electronics shut down, light source for the display is turned off, CPU is slowed down or turned off. Power is reduced by 25% of active mode in standby mode, giving one portable computer, (Model A in Table 3.3), 12 hours of life on a single battery charge (BYTE 1991b).

<u>Suspend mode</u>: Power is used only to refresh memory in order to maintain the state of the computer. Notebook battery lifetime in suspend mode is estimated to be 330 hours per charge by the manufacturer of one portable computer that employs the Intel 386SL CPU, a processor that includes power-management features. This suggests that the power in rest state is about 1% of active power, a conclusion reinforced by a report of 1000-hour lifetimes in suspend mode for computers using the Intel 386SL CPU (BYTE 1992a).

The suspend mode is commonly used by portable computers and is not confined to a particular CPU, as shown in Table 3.3. This table shows which models have certain features, marked with an x when they are available. The way in which this state is entered may differ among computers. For Model A, the power switch can be configured to put the machine into suspend mode rather that turn off completely, providing quick recovery of the computer's state when activity is resumed without the need to reboot. For others, this state may be entered after a time-out period or via a button separate from the power switch. Power management works best with computers that can handle suspend/resume operations without conflicting with normal system operations, and the presence of a suspend mode indicate whether the users would find it acceptable for use when operating the computer.

Table 3.3. Power management features of several portable computers.

Feature	Model A[1]	Model B[2]	Model C[3]	Model D[4]
CPU	386SL	386SL	486SX	386SX
Display time-out	x	x	x	x
Disk time-out	x	x	x	x
CPU speed	x	x	"sleep"	
Standby	x	x	"other"	
Suspend	x	x		x

1. BYTE 1991b.
2. BYTE 1992c.
3. PC Magazine 1992; BYTE 1992b.
4. BYTE 1991a.

Huser reported that the average power requirements for a sample of nine laptops was 16.6W (standard deviation of 2.9 W) without power management, and 11.1 W (standard deviation of 3.4 W) with power management. Two machines are notable; an 80386SL laptop with 20 MHz frequency, 2 MB RAM and 60 MB HD used 20.3 W without power management and 10.3 W with it. An 80386SX, which generally doesn't have power management capabilities, with the same frequency and memory draws only 16.4 W without power management, and 4 W with it, indicating that a CPU with built-in power-management capability is not essential for substantial power reduction. However, the developers of such CPUs note that on-board power management features are designed to preserve the integrity of the operating system and software applications while reducing power levels.

The laptops tested, on average, consumed only a third less power in a power management mode than in ready mode. Either these laptops lacked a true suspend mode or were not measured in this mode. Our own measurements of a 68030-equipped portable showed that this computer required about 2.5 W in its so-called sleep mode (equivalent to suspend mode), compared to a maximum of 13 W when operating. Nearly as much power was drawn when it was completely shut down but still plugged in, suggesting that most of the sleep power was dissipated in the trickle charge provided to the computer.

Robust, easily implemented power management motivated the development of the Intel/Microsoft Advanced Power Management (APM) software specification. Even within portable computers, power management suffers from lack of knowledge about computer activity. Power management decisions, made by the low-level software embedded in a computer's non-volatile memory (so-called "firmware"), are improved with information from the operating system. The APM specification applies to both the operating system and the firmware and, according to its developers, is intended to "extend battery life of portable computers by up to 25% during full-on conditions" (Intel/Microsoft 1992). Despite the stated goals, it would appear that APM, perhaps with modifications, could apply to desktop computers as well. The reference to "full-on conditions" is somewhat confusing in the context of the terminology used in this report. APM is designed to reduce operating power and, of course, will not save power when a computer is completely shut off. But the process of reducing power to unused components will place the computer in what has been designated a standby or suspend mode.

D. Potential energy savings from power management in desktop computers

The introduction of a number of computers meeting EPA Energy Star guidelines makes clear that power management is being incorporated into desktop computers. One machine, with a power-managed 486SL CPU, requires no cooling fan, costs no more than standard desktops machines, and is advertised to use less than 15 W in operation and less than 2 W in suspend mode . The lower power figure is nearly identical to the measured power of a laptop operating in a low-power state with the battery trickle charger. The recent wave of new products satisfies a goal held for several years by energy conservation experts: to bring to the market desktop computers with power management features comparable to those found in portable computers.

In this section we first review guidelines for power management in computers and then identify limitations in how well or how readily power management is now implemented in current hardware and software. These limitations define a need for improvement in the future and a need for some care in consumer selection of products.

1. Guidelines

A detailed document produced by one Energy Star participant (Intel 1993), makes clear what is involved in successful power management. The principals are of interest, even though the implementation is limited to a single vendor's products and alternatives are available from other vendors. The document identifies three guidelines for power management:

a. *No compromise on performance*. Future computers may require more electrical power in peak activity, in line with the previous discussion of the growing functionality of CPUs, but should support power management. The question of productivity is contentious. Some argue that no compromise is acceptable while others note that societies often make certain demands, such as waste separation and recycling, that require some effort that might be considered unproductive. The suspend mode in computers and displays necessarily requires some recovery time, which in some cases delays productive work but can also take place while the user is performing other tasks. In addition, recovery from the suspend mode is faster than the time-consuming boot-up and can thus enhance productivity. We consider the *no compromise* guideline to be sound, within a conceptual framework that distinguishes operating mode, where no reduction in performance is tolerated, standby mode, where near-instant recovery is required, and the lowest-power suspend mode, where longer recovery times are not only acceptable but an improvement compared to prolonged boot-up times.

b. *Software transparency*. Power management should be independent of the software application running on the computer and independent of operating system as well. While some forms of power management may support this guideline better than others, the proof will come with consumer acceptance and use of power management, as quantified in one or more tests of Energy Star products in actual use.

c. *Affordability*. The vendor argues for reasonable rather than unduly restrictive energy-efficiency standards. The Energy Star desktop computer described above achieves near-laptop power levels, indicating that power levels well below the EPA target are achievable today at no increase in cost. Affordability would not appear to be a serious limitation in the transfer of power management to desktop computers.

2. CPU Features for Power Management

CPUs have two roles in power management: to be capable of reducing their own power and to be capable of controlling the power of other components. The "SL" technology that one vendor (Intel) has developed includes both capabilities. This technology is incorporated in the initial design of the vendor's latest CPUs, including the Pentium, which meets the guideline of no compromise in performance (i.e., a less capable CPU) for power management. Previously, power management features were added a year or so after the first release of a new CPU.

Power management of the CPU itself can be implemented by controlling the speed of the CPU's clock or stopping it entirely. Power management can also be achieved by halting the CPU's execution of instructions or, in computer software terms, requiring the CPU to execute HALT instructions that entail no computation. Intel points out that clock control is required to enter the suspend state, where power is fully removed from the CPU, and that clock control therefore promotes CPU power management as part of a software routine that interrupts normal CPU activity.

Power management of peripherals, within the SL framework, is implemented within a System Management Mode (SMM) that includes two features: a special interrupt that can be triggered by computer components or software and secure memory space within the CPU to store the code needed to respond to the interrupts (the Interrupt Service Routine, or ISR). Without the dedicated memory space, an ISR becomes specific to a given operating system and can also be more easily overwritten by other code.

3. Power-Managed Hardware

a. Hard disk drives. Some types but not all hard disk drives can be easily power managed. Hard disk drives built in accordance with the Intelligent Drive Electronics (IDE) specification can go to low power states in response to software signals. Another popular drive specification, Small Computer System Interface (SCSI), requires additional software.

b. Monitors and Video Controllers. The VESA Display Power Management Signaling (DPMS) specification requires that synchronization signals from the video controller to the monitor be turned off as an indication to the monitor to go to a low-power state. This control feature will be included in future video controllers but may require separate logic in the interim. Powering down the video controller itself will require that the video configuration information be stored on the hard disk to permit the video image to be restored.

One manufacturer (HP 1993b) has implemented the DPMS specification in its new personal computers. However, its current monitors cannot take full advantage of the control signals and only save 15-17% when powered down. New-generation monitors will be able to save 95%.

c. Other Peripherals. There is no power management standard for other peripherals, including fax cards, modems, and network cards, that are designed to plug into the standard ISA or EISA buses used in most personal computers based on 486 and earlier CPUs built by Intel and others. Such a standard is needed.

4. Operating hours

The energy-saving potential of power management depends on how computers are used: how long they are turned on and how long they are actually in use. Data on hours of operation have been scarce and actual usage pattern data have been nonexistent until very recently. Tiller and Newsham (1992) of the National Research Council (NRC) of Canada developed software to monitor computer activity and then analyzed the data collected from a sample of 94 computers over a period of 8 weeks. NRC recorded the number of minutes during which there was keyboard or mouse activity for each computer and subsequently calculated reductions in computer on-time that would have been achieved if there had been power management to turn off the computers after a specified period of inactivity. Mean operating times, shown below, were based only on computers that were in use on a given day; a computer turned off over a complete day was not part of that day's calculations. The mean times would be somewhat lower if normalized by all machines each day, including those not in operation.

Operating hours varied from 31 to 84 hours among the three government office sites that were monitored, a reflection of the range in tendencies to leave computers on over night. The average operating period of 53.7 hours was only slightly in excess of the 50-hour period of occupancy often assumed in calculating commercial building energy use. This is an important finding. Even though some computers were left running overnight, others were not powered up during the day. The daytime diversity nearly balanced nighttime operation.

Table 3.4. Weekly Computer Operating Times with Automatic Shut-Down after a Period of Keyboard Inactivity.

Usage pattern	Mean on-time hours/week	Percentage on-time
No power management	53.7	100
60-minute switch-off	22.4	42
15-minute switch-off	14.2	26

Switching off computers after 60 minutes of inactivity would reduce operating time to 42 percent of the base case, while a 15 minute time-out would achieve a further drop to 26 percent of the base case. NRC does not report the estimated savings for shorter time-out periods that portable computers can be set to use. As an extreme case, at least one palmtop and one notebook computer slow the microprocessor between each keystroke. NRC's estimated hours of operation per week under power management were nearly the same among the three sites, indicating a similarity among usage patterns during the workday. That is, were computers at each of the sites to shut down after fifteen minutes of inactivity, they would operate about 14 hours per week. The NRC data should challenge others to perform similar experiments and enlarge the overall sample size.

NRC reported that reminder stickers to turn off computers initially produced a modest energy savings of 14 percent that was not sustained over the eight- week monitoring period. An electrical power strip with user adjustable automatic switching triggered from keyboard or mouse activity reduced computer electrical energy to 32 percent of base case levels and video display energy to only 18 percent. The power strip completely turned off the equipment, forcing the equipment to go through power-up checks and the user to open application programs. Power management provided by a computer's suspend mode requires a more shorter recovery time. The 32 percent energy consumption level achieved with the power strip falls between the values calculated for 60 minute and 15 minute automatic time-out control, indicating that users were willing to turn off and restart computers that were anticipated to stand idle for less than an hour. Koomey et al. (1992) consider potential degradation due to switching in equipment life due to switching a computer and display off. They found this to be minimal for several switching cycles per day, versus extended calendar life due to shorter operating hours. They also consider the lost productivity while the diagnostic checks are underway and argue against powering down for 1-2 hours. Tiller and Newsham stated that productivity, as measured by keystrokes, was not compromised by their power strips.

5. Power-management chips.

Power management can be facilitated with power-management features built into the CPU, although Huser's measurements indicate that such CPUs are not essential in achieving substantial power reductions in portable computers. As an alternative to using a CPU with built-in power management in desktop computers, a separate system controller chip has been introduced that is intended to provide power management capabilities.

E. Summary

Computers, in a small sample, have been shown to be in active use about 14 hours per week (8.3% of all hours) and powered an additional 40 hours (23.8%). Power during operation is as low as about 24 W for a prototype 486SL desktop computer, about 8 W higher than a sample of laptops. (The latter include displays, while the former do not.) Power in suspend mode has been measured as low as 2.5 W for a portable computer. Most of this amount is thought to be used to trickle charge the battery, establishing a lower bound for what desktop computers can achieve. This may go to the power supplies, but in some cases it is conceivable that desktops would go down to 0 Watts. With manufacturers responding to the Energy Star program, differences in power consumption between desktop and portable computers are narrowing.

III. Displays

Displays are evaluated here on the basis of the technology used to create an image: video displays that employ cathode-ray tubes (CRTs) versus several technologies that are used in flat-panel displays. We will consider both monochrome and color displays and determine their energy consumption on an equal-area basis. We will also examine power management possibilities for both types of displays.

A. CRT displays

CRT displays depend on the excitation of a layer of phosphors from an electron beam, which is produced in an electron gun and passed through a control grid to turn the beam on and off. The beam is then focused and deflected by sets of coils and finally, drawn by the large positive voltage on the tube, it strikes the phosphor coating. For color displays, there are red, blue and green phosphor dots, with an electron beam for each. Color monitors use a shadow mask to block stray electrons that might excite a neighboring phosphor. Shadow masks are plates perforated with a number of tiny holes or narrow slits to guide the electron beams. Monochrome monitors do not require a shadow mask, which is a significant source of energy loss that reduces the efficiency of a CRT display. As the resolution of the CRT display increases, more electrons stray from increasingly smaller holes in the shadow mask, further decreasing the energy performance of the monitor. One manufacturer of color CRTs reported in 1988 that less than a third of the electron-beam energy reached the phosphors (Smarte and Baran 1988). On the other hand, another was able to boost brightness by 50 percent by reducing losses.

Monitor visual performance is measured by a number of parameters, of which brightness and efficacy most concern us. Brightness, or luminance, is measured in candelas per surface area or in footlamberts, where the latter is defined as the "uniform luminance of a perfectly diffusing surface emitting or reflecting light at the rate of one lumen per square foot" (IES 1981) and one footlambert equals $1/\pi$ candela per square foot. Efficacy of a display is measured much as is a lamp or lighting fixture, in lumens per Watt. The area-weighted electrical power of a monitor is therefore proportional to the ratio of luminance and efficacy. This is a key point in the following discussion. While the ratio itself is of most interest in assessing electrical power requirements, some understanding of brightness and efficacy will provide a deeper understanding of opportunities to control power.

Howard (1992), in comparing color CRTs with flat-panel displays, stated that the brightness of a CRT display is 400 cd/m^2 (117 footlamberts) and the efficacy is 0.5-3.0 lm/Watt, with the lower value appropriate for high-resolution displays. He later identified a brightness of 100-150 cd/m^2 (29-44 footlamberts) for information display, with values several times higher for television. The average screen luminance of 81 displays, as measured for a trade journal (PC Magazine 1993), was 86 cd/m^2 (25 footlamberts), slightly under Howard's value. The low end of the efficacy range reported by Howard still exceeds values calculated from power measurements for a number of monitors reported by Huser (1991) and shown in Table 3.5. Note that the increase in resolution boosts the power by a little more than 20 percent. Note, further, that power increases by about 50 percent in going from the monochrome displays to color monitors with VGA resolution (640 x 480 pixels) . These color monitors range in power from 48 to 65 Watts, a variation of 14% about the mean.

There is increasing interest in turning off a CRT display that is not in use. The common screen savers protect the CRT phosphors but have a minimal impact on power consumption. CRTs do not respond rapidly when completely powered down, due to the time required to heat the electron emitting cathode. Roturier (1992) investigated the energy consumption of a stand-alone video terminal, consisting of a display, keyboard, microprocessor, memory and input/output ports for connection to a remote computer. The total power for the terminal, with a screen surface area of 330 cm^2 (51 in^2), was 43 Watts, of which 23 W, or 0.70 W/cm^2 (0.45 W/in^2), was attributed to the display itself. Roturier found that 21 of the 23 W, or 91 percent, could be saved in power-management mode under the constraint of maintaining a near-instantaneous restoration of the screen image. In this case, a power management signal turned off the video display card and the coils, or yoke, that deflects the electron beam, while the cathode, requiring only 2 W, stayed hot. After input from the computer or keyboard, the display image was restored within one second. The logic board, with microprocessor and memory, was not affected. Further testing would be required, per Roturier, to determine the long-term effect of switching. Roturier noted that a similar automatic switch could be used in microcomputers with CRT displays. He described a personal computer display that required 63 Watts, nearly all of which could be turned off, as was done for the terminal. Roturier's work suggests that very significant power savings, associated with what VESA defines as a suspend state, can be achieved under fast-recovery standby conditions.

Table 3.5. Electrical Power for Color Displays.

Type	Diagonal length inches	Resolution	Sample size	Power Watts	Power[1] Watts/cm^2 (Watts/in^2)	Efficacy[2] lm/W
Monochrome	14		9	36	0.058 (0.38)	0.53
Color	14	640x480	12	55	0.090 (0.58)	0.34
Color	14	800x560 and larger	10	67	0.11 (0.71)	0.28

1. Power normalized by surface area is calculated by converting the diagonal length to surface area with an aspect ratio of 4:3.
2. Efficacy for CRTs is based on an assumed brightness of 100 cd/m^2 (29 footlamberts). A theoretical maximum for efficacy from Murdoch (1985) is 683 lm/W, which would produce a yellow-green light. This number is two orders of magnitude higher than the efficacy for a monochrome CRT.

The Energy Star program requires participating manufacturers to produce displays that use no more than 30 W in standby mode in order to qualify for EPA's endorsement. For a 14-inch diagonal color display, 30 W represents about 50 percent of normal operating power. The National Board for Industrial and Technical Development (NUTEK) in Sweden has initiated a more stringent program that requires that automatic standby be adjustable, from 5 to 60 minutes after last use of the keyboard, that the screen be restored within 3 seconds of keyboard or communications port activity, and that power consumption in standby be a maximum of 30 percent of that required in normal operation, not to exceed 60 W. If there has been no keyboard activity after 60 minutes, the display should be powered down to a suspend state (maximum of 5 W), with the time for screen restoration to be similar to that needed when the computer is turned on. Automatic control is required to have no significant impact on the lifetime of the monitor (NUTEK 1992). If there is indeed no degradation, reduced operating hours will prolong the useful life of the monitor.

There are currently six monitor distributors that have responded to NUTEK's program and two provided specifications to us. One 14-inch color monitor uses 75 W maximum in operating mode, less than 13 W in standby, and less than 2.5 W in suspend mode. These numbers show savings of 97%, slightly in excess of Roturier's 91%, but required that heater power be turned off. Again, high energy savings have been achieved with rapid image restoration. These monitors use an internal microprocessor that looks for a signal from a screen-saver program running in the computer.

The second manufacturer's specifications call for shutting down deflection circuitry and reducing the heater voltage in standby, with power reduced to 10 W. Heater voltage will be reduced to zero when the monitor powers down. Potentially adverse effects on the CRT, if present, could be caused by reduced heater voltage, according to this manufacturer.

B. LCD flat-panel displays

Flat-panel displays can be fabricated with a variety of technologies: liquid crystals (LCD), plasma, and electroluminescent emission (EL). An LCD takes light from a light source at the rear of the panel, polarizes that light, and sends it into a grid of liquid-crystal cells. The orientation of each crystal can be controlled by an electric field applied through a grid of electrodes or *passive matrix*. Crystals that are twisted to line up with a second polarizer at the front of the panel to transmit light; those that do not, appear to be dark. Passive-matrix screens necessarily suffer from lower contrast as resolution increases, due to voltage "cross talk" that stems from using the electrode grid to address the pixels (Depp and Howard 1993). A variant of LCD technology relies on an *active matrix* of thin-film transistors to control each pixel of the display. Reflective LCD displays require no back-lighting, saving nearly all of the display's electrical power, but are relatively dim and sensitive to ambient lighting conditions. For a color display, each liquid-crystal cell has an associated color filter and three cells are needed to produce red, blue and green images. An ideal polarizer, needed to control the orientation of the liquid crystals, transmits only one-half of incident light and an ideal filter transmits only one-third of the light. Howard observes that the back-light diffuser has an efficacy of about 40%, the polarizer typically transmits 40% of incident light, practical filters have a transitivity of 24%, and the useful area of a liquid crystal cell is only 50%. The fluorescent-lamp efficacy of 50-70 lumens/Watt is therefore degraded to 1-2 lumens/Watt for the display in its entirety. For a monochrome display, without the filters, efficacy is improved four-fold (Van Name and Catchings 1990). Howard has noted that LCD displays can be comfortably operated at a brightness of 60-100

cd/m^2 (18-29 footlamberts), or about two-thirds the value for CRTs, because they are better able to reject ambient illumination that creates glare and reduces contrast. Pleshko (1989) uses a lower luminous output of 50 cd/m^2 (15 footlamberts) as a minimum standard for flat-panel displays. Using an efficacy of 1-2 lumen/W and luminous output of 50-100 cd/m^2, we estimate that color LCD panels would require 0.008-0.031 W/cm^2 (0.05-0.20 W/in^2) and monochrome displays 0.002-0.008 W/cm^2 (0.01-0.05 W/in^2). To these figures must be added the power required by the transistors and circuitry that interfaces with the computer. Tannas et al. (1992) noted that a 38 cm (15 inch) color LCD monitor required 20 W for the back-light and 26 W for the electronics, for a total of 0.075 W/cm^2 (0.48 W/in^2). A 26.4 cm (10.4 inch) LCD color display about to be marketed for use with desktop computers is reported by the manufacturer to require 23 W, or 0.068 W/cm^2 (0.44 W/in^2).

Passive-matrix displays use the same color filters and are slightly more efficient. Examples of this technology that were reviewed three years ago were branded as relatively slow and plagued with low contrast (15:1) and washed-out colors (Jones 1989). Both passive-matrix and active-matrix LCDs can be powered up and down as part of the computer's power management system. Screen recovery time is very rapid, approximately 1 or 2 seconds.

A new LCD display developed by researchers at Kent State University requires no back-lighting, but provides better contrast than earlier displays that lacked back-lighting by utilizing a polymer-stabilized cholesteric liquid crystal material. The image can remain displayed on the screen indefinitely without requiring an additional electronic charge. Work is under way to develop full color displays with this technology. In this paper, we will limit our discussion to active matrix displays, because of their more advanced development and availability and acceptance in the market place.

C. Plasma and EL Displays

Plasma displays operate by exciting pixels of plasma via applied high voltage, a process that is less efficient than liquid-crystal displays (Smarte and Baran 1988). Color plasma displays use ultraviolet light from the plasma to stimulate phosphorescent coating, much as a fluorescent lamp (Depp and Howard 1993). EL displays are completely solid state devices, in which phosphors produce light in the presence of an alternating electric field.

Efficacy is claimed by some authors to exceed that of plasma displays but lag LCDs (Smarte and Baran). For monochrome displays, both EL and plasma offer reduced power when (as is typical) not all pixels are illuminated, an advantage not shared by LCD panels. In both technologies, light is emitted by each pixel, in contrast with LCDs, where the individual pixels act as shutters. Both plasma and EL displays do not offer high-quality full color. Howard notes that there have been difficulties in producing full-color plasma displays and that EL, while very rugged and offering high contrast, has been stymied by the lack of a suitable blue phosphor.

One manufacturer chose to develop monochrome EL rather than plasma displays because of a reported 10:1 advantage in luminous efficacy: 3 lm/W vs. 0.3 lm/W for plasma (Sands 1990). Von Stroh (1988) also gave the advantage to EL over *direct-current*-powered plasma displays. He claimed that the former have 2.5 times the brightness and require only 40% as much power, for an efficacy ratio of over 6:1.

Friedman (1990) disputed the efficacy advantage of EL and estimated the efficacy of a monochrome EL display as 0.6 lm/W and that of a monochrome plasma screen driven by *alternating current* as 0.7 lm/W, based on a detailed accounting of the luminous flux. Friedman claimed that the plasma screen offered three times the brightness when measured normal to the screen (15 versus 5 footlamberts) and that the plasma screen's luminous output was a factor of 2.4 higher than such a measurement revealed, due to substantial off-normal radiation. By taking the ratio of brightness and efficacy, the plasma screen would then require 0.056 W/cm^2 (0.36 W/in^2) and the EL screen 0.009 W/cm^2 (0.06 W/in^2) at full power, with all pixels illuminated; for the same luminous flux, the EL display would require 0.067 W/cm^2 (0.43 W/in^2). The fact that different authors have different views, each backed by numbers, suggests that uniform measurement procedures are needed. For example, off-normal luminous flux in excess of a perfectly diffusing surface will improve off-normal visibility but may be of little benefit to a single user in front of the display. In this case, taking credit for this flux distorts the efficacy calculation.

Importantly, both plasma and EL displays run at reduced power when fewer pixels are lit, unlike LCDs with constant back-lighting. Friedman's plasma display offered part-load performance superior to an EL, requiring less power than an EL display of the same size with 5 percent pixel illumination. Pleshko (1989) uses 15 percent pixel illumination as a typical value and confirms that plasma screens, by going to about 24 percent full-load power, offer more power reduction than an EL display, which drops to 58 percent.

The 48 cm (19 inch) monochrome EL display that one manufacturer introduced in 1990 required about the same amount of power under full load, 65 Watts or 0.059 W/cm^2 (0.38 W/in^2), as a conventional CRT (Sands 1990). A French version of the monochrome EL display includes a thin photoconducting layer to improve brightness, contrast and efficacy. Power consumption was estimated to be a minuscule 0.006 W/cm^2 (0.04 W/in^2) for a brightness of 50 cd/m^2 (16 footlamberts) and 0.047 W/cm^2 (0.30 W/in^2) for a brightness of 325 cd/m^2 (103 footlamberts), about 10% of the 0.071 W/cm^2 (0.46 W/in^2) for a conventional EL panel (France Telecom 1989).

D. Comparison

For monochrome displays, the area-weighted energy consumption of LCDs offers a clear advantage over CRTs. Plasma and EL displays also offer lower energy consumption than CRTs under typical part-load operation. LCDs are about 4 times as efficacious as CRTs and, importantly, operate at lower luminances, about two-thirds that of CRTs.

With a strong trend toward color displays, EL displays are no longer competitive in the marketplace. Howard (1992) would eliminate plasma as well, both for lack of full color and no clear power advantage relative to LCDs. In fact, there appears to be an industry consensus that color LCD has emerged as the winner among flat panels (Tannas 1992). The color LCD panel at 0.068 W/cm^2 (0.44 W/in^2) represents a clear benefit over a CRT at 0.09-0.11 W/cm^2 (0.58-0.71 W/in^2). For monochrome, removing the filters required for color LCDs appears to have more of an impact than removing the shadow mask for CRTs. As indicated in Table 3.6 and its notes, measured power for monochrome LCDs, 0.014 W/cm^2 (0.09 W/in^2), is less than 25% that of monochrome CRTs, 0.059 W/cm^2 (0.38 W/in^2). LCDs benefit from producing satisfactory images at luminances that are lower but still in compliance with the ISO standard of 35 cd/m^2 (10 footlambert) at lowest gray level.

Power management offers a slight advantage to LCDs, due to shorter recovery time. CRTs offer near-instant recovery only when in an intermediate standby mode (as required by the NUTEK program), and can eliminate essentially all of the power in a suspend mode that may require as much as a 30 second recovery time. For either LCDs or CRTs, a screen that is darkened as part of standby or suspend modes leaves the user with no visual clue that the associated computer is still powered. Status indicators might remind users to fully power down their equipment when no usage is anticipated for a long period.

Table 3.6. Electrical Power for Displays.

Technology	Luminance cd/m^2 (footlambert)	Efficacy lm/W	Power[1] W/cm^2(W/in^2)
Monochrome			
LCD	50-100 (15-29)[2]	4-8 (calculated from color and absence of filters)[3]	0.002-0.008 (0.01-0.05)[4]
Plasma	120 (36)[5]	0.7	0.056 (0.36)[6]
EL	17-50 (5-15) (conventional) 50-325 (15-103) (photoconductive layer)	0.6 2.5	0.023-0.071 (0.15-0.46) (conventional)[7] 0.006-0.047 (0.04-0.30) (photoconductive layer)
CRT	100-150 (29-44)	0.53-.80	0.058 (0.38)[8]
Color			
LCD	50-100 (15-29)	1.0-2.0[3]	0.008-0.031 (0.05-0.20) 0.075 (0.48) 0.068 (0.44)[9]
Plasma	50-120 (15-36)	0.2-0.4[3] 1.5[10]	0.040-0.194 (0.26-1.25)[11] 0.011-0.026 (0.07-0.17)
EL[12]			
CRT	86-150 (25-44)[3]	0.28-0.34[8] 0.5-3.0[3]	0.09-0.11 (0.58-0.71)[8]

1. Power is calculated as ratio of luminance and efficacy.
2. Pleshko's value is 15 fL, while Howard's upper bound of 100 cd/m^2 translates to 29 footlamberts.
3. Howard. Luminances for color CRTs are supplemented with data from PC Magazine (1993).
4. Calculated from luminance and efficacy. Data presented by Kardon (1989) show power of 0.005 W/cm^2 (0.03 W/in^2) for an LCD with electroluminescent back-lighting and

0.014 W/cm^2 (0.09 W/in^2) for cold-fluorescent lamp back-lighting. Our own measurements of an active matrix LCD showed 0.014 W/cm^2 (0.09 W/in^2).
5. Luminance of 15 footlamberts and Friedman's factor of 2.4 to account for non-Lambertian radiation. The factor gives full credit to off-normal emission that expands the viewing angle but does not contribute to brightness when the screen is viewed at the normal angle.
6. At typical pixel illumination, Friedman would calculate a power of 0.012 W/cm^2 (0.08 W/in^2) and Pleshko (1989) a power of 0.019 W/cm^2 (0.12 W/in^2). Watkins (1988) gives a 5:1 power advantage to monochrome LCD (with back-light) over plasma. This ratio agrees with the data presented here for typical part-load illumination.
7. Friedman, Sands, Schlam (1989) and France Telecom. The power levels are all higher than would be calculated from luminance and efficacy. Schlam's power defines the lower end of the range.
8. Huser. Efficiencies are calculated from measured power and assumed luminances.
9. The range of lower values is calculated from luminance and efficacy. The highest value, which includes power for electronics associated with the display, is derived from Tannas et al. (1992) and the slightly lower value from manufacturer's specifications.
10. Weber (1989).
11. Powers are calculated from luminance and efficacy. The range of luminance is based on the factor of 2.4 that accounts for off-normal luminance flux in excess of a perfect diffuser.
12. No color EL available.

While reduced electrical power, energy use, bulk and weight are all on the side of the LCD, CRTs are available in larger sizes and at lower cost. Despite improvements in manufacturing yields, the cost of color LCDs is expected to remain in the near term at least five times that of comparable CRTs (Tannas 1992), although there is some difference of opinion about the duration of the "short term.". One factor in the cost of LCDs is the higher energy consumption to fabricate an LCD display. Tannas et al. (1992) present data from one manufacturer, shown in Figure 3.2, that indicate that the total energy cost to fabricate and operate an LCD display equals that of a CRT, for a product life of 5 years and five hours per day of use. Continued viability of CRTs argues for increased attention to power management and to the range of power requirement for comparable models, reported by Huser as being about $\pm$14 percent.

Conditions:
Total Domestic Usage in Units: 50,000,000
Production in Units: 10,000,000 per year
Product Life: 5 Years
Hours in Use: 5 Hours per day

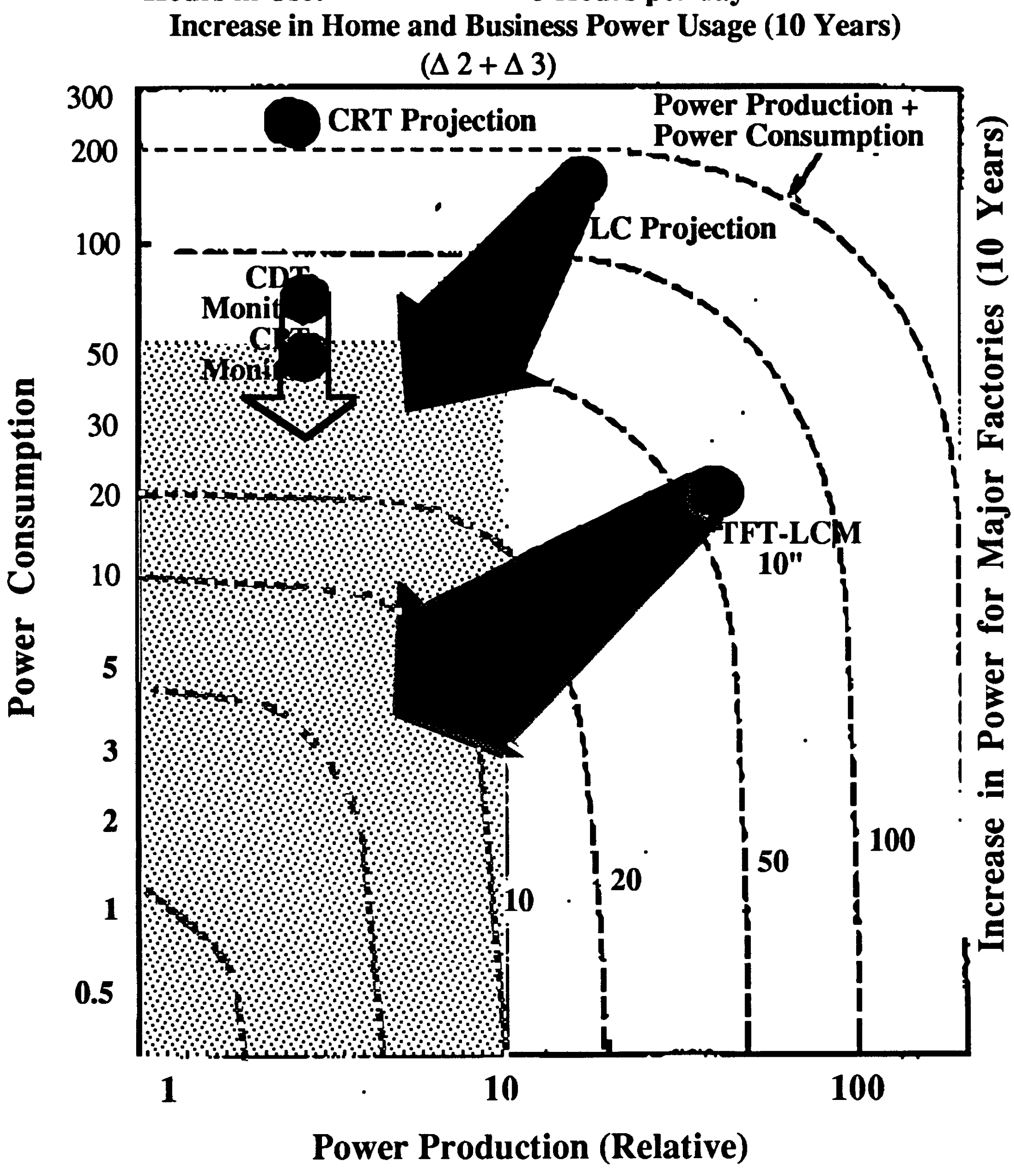

Figure 3.2. Electrical Energy Required to Produce and Operate Computer Displays (Tannas et al. 1992). Thin-film transistor, active-matrix displays (TFT-LCM) require at present about the same life-cycle energy as CRTs. Passive-matrix displays (STN-LCM) are more efficient.

E. Future Display Technology

For both CRTs and flat-panel displays there is a trend toward larger screen sizes in response to the widespread acceptance of graphical-user interfaces and growing applications for multimedia presentations. Beyond this, Depp and Howard (1993) speculate that flat panel displays will, when combined with data storage, replace repositories of paper. They further note that wall-mounted, large displays may serve as a changeable art gallery or wallpaper when not serving as a television or computer monitor. Some versions of the office of the future include electronic display boards, or "live boards" that would replace chalk boards and offer communication to remote sites (Potts 1992). Energy analysts and utility planners have reason to be concerned about the increased electrical power required by more numerous displays, particularly large units. For example, a color LCD panel of 1 m^2 surface area would require 700 Watts if it matches the performance of today's color LCD monitors.

Recently, an ultra-thin CRT was developed that uses cold electron emission from a large matrix array of micro-guns or "microtips" (Vaudaine and Meyer 1991). It also uses low voltage cathode luminescence (400 V for the anode-cathode voltage compared to 20 kV for a CRT). Light is produced from cathodoluminescent phosphors. There is a very small distance between the front glass plate and the rear glass plate where the microtips are located (roughly 2 mm). So far, a 6-in. monochrome display working in TV mode has been demonstrated. By using pulse width modulation method, the 16 gray levels required for computer monitors can be produced. Recent improvements have suggested that the power consumption could be under 0.02 W/cm^2, compared with 0.06 W/cm^2 for a conventional monochrome CRT and about 0.014 W/cm^2 for a monochrome LCD. A full color monitor using this technology is also possible. Other positive aspects of this new technology are that brightness, contrast and the viewing angle are insensitive to the size, and that it has a very fast response time (a few μs for a display area as large as 1 m^2). One disadvantage is low contrast under high illumination.

IV. Environmental Management

A. Production issues with Office Equipment

Manufacturing processes for the production of office equipment are known to produce excess plastics, heavy metal, CFCs and solvents that are dangerous to the environment. Energy and materials wastage, atmospheric and water pollution are also part of the environmental impact of the manufacturing process. One source says that the manufacturing process may be more energy intensive per piece of equipment than the energy use during the equipment's usable lifetime.

It is important when considering the energy use of office equipment in manufacturing to look not only at the electrical energy used, but also potential energy savings from the recycling process. We will examine the energy consumption of various processes in the manufacture of a computer, but also look at recycling efforts that may reduce energy consumption by the reuse of parts and equipment.

Green design is becoming a focus for manufacturers, in a large part due to increasingly stringent regulations (Environmental Consciousness 1993). The Office of Technology Assessment (OTA 1992) states that "green design is likely to have its largest impact in the context of changing the overall systems in which products are manufactured, used and disposed, rather than changing the composition of products per se." In one study (Environmental Consciousness 1993), energy consumption, material usage, waste water production and hazardous and non-hazardous waste production was analyzed through a questionnaire distributed to various computer manufacturers. Not included in the analysis were the manufacture of disk drives, power supplies, electrical cables, brackets, housings, keyboards, mouse and all passive electrical components. While this material accounts for 28 % of the workstation's weight, and may play a significant role in any part of the study done, most of these materials were beyond the control of the participants of the project.

The following table outlines the energy consumption of a workstation during production. The numbers do not include the energy required to process raw materials.

Table 3.7. Energy costs of workstation production (Environmental Consciousness 1993)

Sub Component	Energy (kWh)
Semiconductor	290
Semiconductor Packaging	1790
Printed Wiring Board	60
Display	180
Total	2320

As an illustrative calculation, the energy consumed by a 300 W workstation, on 3000 hours/year, for 6 years is 5400 kWh, a little more that double the amount of energy it takes to produce the portions of the workstation shown above. If the workstation is power managed, using only 30 W for 60 % of the time it is on, it would use less than 3250 kWh, more comparable to the amount of energy used to produce the computer. Energy consumed in the recycling process is at this point unknown, but since current regulations require that the lead from the CRTs not be placed in landfills, a certain amount of recycling will happen anyway. If there is recovery from that process, it can only be beneficial.

Environmental management also includes mandated limitations on certain materials. The EEC has a proposal to ban all PBBE plastics. ICL, a computer manufacturer currently does not use such plastics nor does it spray EMI shields, thus avoiding complications in recycling the plastic housing for the shield. It is beginning to label plastic for recycling, and is using water based solvents for the washing process, instead of CFCs. It has a computer recycling program which is based in Germany.

Government regulations and good corporate citizenship are prompting companies to produce, package and reclaim computer equipment in an environmentally responsible manner. An EEC packaging-waste regulation requires companies to take back and recycle or re-use packaging used to transport equipment. A German law, expected to be in force in 1994, will require companies to take back obsolete equipment at a cost included in the purchase price and to recycle or reuse the equipment. And, by 1995, the Netherlands will ban the brominated flame retardant used in plastic computer cases, monitor shells and keyboards. To promote compliance with environmental regulations, the British Standard Institute (1993) has developed a specification that includes "requirements for the development, implementation and maintenance of environmental management systems aimed at ensuring compliance with stated environmental performance criteria." An environmental management system is, in essence, a series of procedures and instructions for verification, measurement, testing, record-keeping, audits and reviews. The Standard should be used in wide practice in Europe within the next few years.

Interestingly, the phase-out of CFCs as a cleaning agent to remove solder flux form circuit boards has reduced cleaning costs and improved yields (Perry 1993). Alternatives include using water as a cleaning agent, with organic fluxes, and modifying the flux composition and application to require no cleaning at all, a strategy adopted by Apple and Compaq.

One company, Hewlett Packard (1993), has documented its environmental strategies and described what it calls its new personal computers. These are designed to be upgraded rather than replaced outright, are easily disassembled into separate materials, are free of hazardous materials and, notably from an energy perspective, support partial power-down of monitors. In addition, HP is developing what it calls comprehensive power management for its next generation of products, reducing energy use below what is required today by products that meet the Energy Star guidelines.

HP has two recycling plants, where 93% of incoming equipment is reused as repair parts or recycled. The remaining 7% includes 2% for CRTs, for which, according to HP, no viable recycling technology exists, and incineration and landfill for the last 5%. No data were included on the fraction of new equipment returned to the facilities, an important figure in calculating the energy embodied in office equipment. In addition, HP recycles laser-printer cartridges, which can be returned at no cost to the user. Some pieces are reused in new cartridges and others are melted for reuse as raw material.

Digital Equipment Corporation (DEC) is also involved in recycling. According to a representative at its European plant, a large percentage of equipment taken back from the user is reused or recycled, but only about 10% of DEC equipment is actually taken back. In order to have highly efficient product disposal centers, a disassembly process that is highly structured and automated is necessary. Models for such systems are currently being formulated, but high volume is necessary to make the system efficient. However, increasing volume could also create more energy problems associated with transportation.

DEC is currently looking into new designs and systems to create a more environmentally sensitive product. The product disposal centers are giving input to designers about problems associated with reuse and recycling, but they are not able to drive the design of new equipment. One possible option for increasing the environmental efficiency of a design would be to make the design group responsible for the cost of disposal of the system. Now, costs of take-back equipment are overhead costs, so improving designs to suit recycling has no monetary value. If improvements are not related to costs, environmental design groups will fail. Apple computers just eliminated its Designs for the Environment group, primarily because it didn't relate design improvements to costs.

IBM, NEC, Xerox, and several other office equipment manufacturers also have recycling efforts in place. IBM, for instance, is incorporating many of the ideas mentioned above into the designs of their new computers. NEC has set up a program to improve the disassembly process of the computer, while Xerox is heavily involved in recycling cartridges and remanufacturing their copiers.

Using different material could also cut down on the electricity use of the computer. Materials such as thermal plastics that would not need to be cooled externally, would eliminate the need for fans thus cutting down on the electricity needed for the computer, as well as cutting down on energy costs related to production of the computer (Ferrone 1993).

B. Embodied Energy in Paper

Nordman (1991), basing his work on information from Giese, has calculated that a single sheet of plain paper requires 10 - 20 Wh of energy to produce, far in excess of the 0.1 - 2.3 Wh that most office equipment requires to print a page. Here, printing energy refers only to the energy required to generate and fix an image and does not include energy used during standby. With standby losses included, copiers, printers and faxes may use more energy to print a page of information than was required to make the paper if the printing volume is low,. Table 3.8 highlights Nordman's data on thermal and electric contributions to paper production as well as data from NUTEK.

Table 3.8. Total Process Energy Values for Kraft Paper.

	Thermal	Electric[3]	Total
Nordman calculations			
MWh/ton	4.7 - 9.7	0.2 - 0.5	4.9 - 10.2
Wh/page[1]	9.4 - 19.4	0.4 - 1.0	9.8 - 20.4
NUTEK calculations			
MWh/ton	3.0	1.0	4.0
Wh/page[2]	15.0	5.0	20

Notes:

1. Calculations for these values were made by using the following numbers: .293 Btu/Wh, 200,000 sheets/ton, 4.5 g/sheet, 220.954 sheets/kg, 100 sheets/lb, 500 sheets/ream.
2. Calculations for these values were made by using 5 g/A4 sheet.
3. This is assuming hydroelectric electricity generation.

For a in depth look at the breakdown of thermal and electrical energy use in pulp and paper process, see Table 3.19 in Appendix C.

The electric and thermal energy required to produce paper also varies regionally, within the United States. Mills which are located in areas where electric power is less expensive, such as the Pacific Northwest, will tend to use proportionally more purchased electric power. Some distinction should be made between electric power generated by hydroelectric versus thermal sources. If the electrical power is produced by a hydroelectric power plant, then the electric energy used to produce paper or to print a page is as listed. However, if the electricity is produced by a thermal power plant, the fuel energy usage must be multiplied by about three, to account for power plant inefficiencies, in order to yield a figure that can be properly added to the thermal energy. Using this information, 11-35 Wh of energy would be required to produce a page of paper and 0.3-7 Wh to print a page, in both cases with electricity from a thermal power plant. For electricity produced by co-generation, the embodied energy will fall between these levels and those shown in the table above.

Energy consumption in office equipment ascribed to paper can be reduced by cutting back on the amount of virgin paper that a copier, printer or fax uses. Paper making with recycled paper fiber requires about 40% of the energy that virgin materials need (Knickerbocker 1993). However, the fibers in recycled paper are more difficult to align and do not bind together as well due to higher dust content. Manufacturers of some laser printers recommend that new paper be used in their machines, although this paper can have recycled fiber. Other machines, including ion deposition copiers, ink jet imaging equipment, and some laser printers, can print copies on the reverse side of previously used paper, although copiers that have difficulties with duplexing are subject to jamming with previously used paper. Thermal fax machines require thermal fax paper to receive documents and some color printers require specially coated paper. Both of these special papers have higher embodied energy content than virgin paper due to the additional coating processes.

C. Recycling

1. CRTs

ICL and HP both state that monitors present the biggest recycling problem, because the glass from a CRT contains too much lead and strontium to be recycled (1992, 1993). However Mytek, one of Phillip's subsidiary companies, recycles glass from CRTs for DEC's European plant.

Because of the lead found in the glass of color CRTs, the EPA is enforcing new regulations forbidding their disposal in landfills. Since the CRT is 85 % of a monitor's weight, the best solution to proper disposal of a monitor is through recycling and remanufacturing (Forrester 1993). In fact, a CRT that is remanufactured is often equal to or superior to the original tube, since the rapid improvements of the electron gun used in the CRTs are ensuring that the replacement gun is better than the original. Also, superior phosphors often ensure better units.

Remanufacturing replacement tubes for the CRT is often very cost effective as well. Used tubes may cost less than a third of the selling price of new tubes. However, if the color CRT tube is not under vacuum, and has phosphor burns, then remanufacture is not cost effective. There are often 40 or 50 types of tubes in production at any time for the remanufacturer, so color re-screening is often out of the question since the remanufacturer would have to have all types of screens at any one time.

Burning of the tubes needs to be detected for cost effective remanufacturing. A computer may sit for hours with the same pattern burning into the screen. If early inspection of the screen reveals these phosphor burns, the tube should be replaced before the damage is irreparable.

Monochrome tubes with bad phosphor burns have another problem; once the phosphor is burned away, the electrons bombarding the glass face will actually change the molecular structure of the glass. Therefore, the old burn will be left when new phosphor is applied to the tube. This can be solved through a process similar to that of manufacturing a new tube. However, as is the case with color tubes, the most cost effective solution is to remove the tube before the damage becomes serious.

Remanufacturing tubes is not the only option for recycling the CRT. Technology is available now to completely disassemble the color tubes for reuse. The funnel, which contains the most lead, can be separated from the panel, thus cutting down on the amount of glass that needs to be directed to hazardous waste sites. The panels could then be resorted, resurfaced, and re-phosphored in quantity, and reassembled with a new funnel. However, large quantities of each type would be necessary for cost effectiveness. If standards were set so recovered glass were more uniform, glass could simply be sorted by formula, making the process much more cost effective.

Even if direct replacement CRTs are not available, adapting similar tubes to the monitor is often possible.

2. Paper

Paper recycling is on the rise, but most of that increase is related to recycling of low grade materials such as newsprint and paperboard. Since 1988, there has been greater than a 90% increased in recycling of low grade paper (ASTM 1993). However, there has only been a 6 to 8% increase in high grade paper used for printing and writing. This is not because the quality is degraded when including recycled paper in high grade products, as producers of light-weight coated grades have developed 10 to 15% inclusion capabilities in their product. Recent developments in have made it possible to process copying and printing papers with greater success.

One of the main reasons we are not seeing such a marked increase in high quality paper recycling, is because only paper machines producing less than 250 tons per day currently manufacture high grade paper with recycled content. Recycled content means specifically that the end product contains the 50% waste paper EPA minimum content requirement. Machines with higher production levels are not currently producing high grade paper with recycled content. This has provided an interesting result. These smaller production machines which normally would have been put out of service, have found a new market window. Unfortunately, if these machines continue to be the only ones that produce recycled paper, the price comparison between virgin and recycled paper will not likely converge. The question of how to bring high production machines into use for recycled paper remains.

Currently, the public sector, including state and federal government offices, is mandated to purchase recycled paper. It currently procures 10 to 12% of the industry's printing and writing capacity. The production capacity of the smaller machines represent about 12% of the production capacity. In order to provide a wider market for recycled paper, the private sector needs to adopt public sector purchasing guidelines. One recycled paper company has developed an approach to bring in the private sector, developing a detailed ranking system, which will provide purchasers better criteria for making a more informed purchasing decision. This system is also supported by the EPA.

The American Forest and Paper Association recently introduced an initiative through its printing and writing division to identify 'recycled paper' as that which contains a minimum of 50% recovered or 10% post-consumer paper. This definition may soon change, however, as recycling advocates claim the inclusion of recovered paper weakens the standard. They would prefer the definition to read instead, "processed recovered fiber". Until this issue is resolved, it will be difficult to move forward in developing policy recommendations for recycling of high grade paper products.

V. Copiers, Fax Machines and Printers

A. Technologies

Copiers are distinguished by how printed information is fixed to a sheet of paper. The most common type of copiers are those that use a combination of heat and pressure to fuse the toner to the paper. There are also ink-jet copiers, which spray microscopic droplets of ink onto paper, and liquid-ink copiers which fuse the toner to the paper through heat. The same technologies apply to printers and faxes. This report will present energy performance data for these technologies. In addition, the discussion includes a brief review of several additional types of monochrome and color printing technologies. Subsequently, separate sections will present power and energy data. Throughout, "printing" will refer to the process of transferring an image to paper, whether it be in a copier, printer or fax, while "printer" will refer to a class of equipment.

1. Heat-and-Pressure Copiers, Printers and Faxes

Electrophotographic copiers form an image using a laser or a moving tungsten halogen lamp which is scanned with mirrors and focused on a photosensitive drum. Toner is electrostatically adhered to the photoconductor, and then transferred to a sheet of charged paper. Finally, the toner is fixed to the paper through heat and pressure fusing. Faxes also scan an image, which is then transmitted and printed. Printers start with a bitmapped image and print it. Laser or LED printers and faxes use the same technique to fix an image as heat-and-pressure copiers. One LED printer has an amorphous silicon (A-Si) drum with a long lifetime and a cartridge that is not disposed or recycled. The ceramic toner is reported to continuously clean and recondition the print drum during use. There is less waste and lower operating costs, but the drums are expensive to repair or replace if damaged.

As will be shown in more detail later, printing energy for heat-and-pressure copiers we have evaluated ranges from 0.2-0.8 Wh/page. For laser printers, printing energy varied from 0.3-0.6 Wh/page, while laser or LED faxes required only 0.1 Wh/page to print a page. These energy data are for monochrome printing. A four-color print requires four passes through a machine and roughly four times as much energy.

2. Power Management in Printers and Copiers

Also of interest is how much power, on average, is required by heat-and-pressure imaging technologies when a machine is not in use. This standby power will translate into a standby energy per page, which depends on the number of pages printed and the time that a machine is on but not in use. Heat-and-pressure printing requires that the fixing drum be heated to approximately 200 °C to fix the toner to the paper. In standby, the imaging device is not printing but the fuser unit is kept hot. In a suspend mode, commonly called an energy saver when used in copiers and printers, the temperature of the rollers may be lowered after the copier or printer has not been used for a specified amount of time, or when the user presses a key on the control panel.

The presence of a suspend mode is no guarantee that it will be used. Copier speed, a key parameter in determining machine performance, is typically specified on the basis of the condition in which the copier is shipped from the manufacturer. Because it takes the rollers time to warm up again from the suspend mode, manufacturers usually ship the copier with this mode disabled. A solution to this problem would require that a test of time-to-first copy be made with the energy saver mode disabled and the copier be shipped with the suspend mode enabled. Often, a technician has to come to the site to enable the suspend mode when the machine is shipped and installed with the suspend mode inactivated. Thus it is reasonable to assume that the mode is frequently never enabled. One manufacturer claims, however that their technicians usually enable the suspend mode when a copier is installed.

Given the thermal dynamics of the fuser unit and a desire on the part of manufacturers to minimize the time required to heat the fuser unit to initiate of a printing sequence, the fuser unit is often kept at temperatures well above ambient in suspend mode. Data for a product line of heat-and-pressure copiers from a single manufacturer show that suspend mode uses 59-79 % as much power as standby mode (Bundesamt fur Energiewirtschaft 1993). This ratio could be reduced if the temperature of the fuser unit could be restored more rapidly to operating levels. A detailed disaggregation of standby power indicates that the heater required 78 % of the standby energy for one copier tested. One light-duty personal copier uses a so-called surface fuser which heats up very quickly. A similar fuser, described in detail in a patent application (Iiumura et al. 1988), employs as a heat source a metallic-ceramic layer on the fusing roller surface in lieu of a tungsten-halogen lamp inside the fuser unit. The fuser unit temperature can be boosted from 50 to 200 ^{o}C in 22-40 seconds, depending on the thickness of the fusing rollers.

Printers may utilize low thermal mass fusing rollers more easily than copiers. A clear indication of the benefit of a low thermal response time comes from at least two laser printers with very low power in suspend mode. One, included in the energy calculation tables presented later in this report, uses only 7 W in suspend mode and 43 W in standby, for a ratio of 0.16. The Bundesamt fur Energiewirtschaft report estimated that a fusing roller designed for fast thermal response and low losses could reduce standby energy by 90 percent, a slightly more ambitious performance than that achieved to date. Two, newly released printer draw 5 Watts in suspend mode, one of which is activated 15 minutes after a print job (Eglowstein 1993). One printer vendor, has developed software for its high-end laser printers to put the printers into a suspend mode. The standby mode uses about 80 W and the suspend mode 25W, a savings of about 70%. Both power levels are somewhat higher than that achieved by the most energy-efficient laser printers (including the one mentioned above), which have suspend modes of 5-7 W. The residual power is required to maintain the printer's electronics. However, this printer is intended to remain turned on all the time and lacks an on-off switch, so it draws 5 Watts even when it could otherwise be completely shut down. Further, the time intervals between print jobs will determine the amount of time that the printer is in suspend mode.

Copiers need to heat up more quickly than printers, because printers take some time to receive and format a page of information. There is a need for rapid response to a start-of-job signal, with no grace period for job formatting (unless the copier first scans the image, digitizes it, and then prints multiple copies from the electronic image, a technique better suited for large jobs). Power management for copiers may require new or improved image-transfer technologies. One method to encourage the development of these technologies and to recognize their implementation is to quantify the benefits of power management via energy-consumption test procedures. Our work with ASTM to revise the copier test procedure initially included the assumption that a copier equipped with an energy saver would drop into the low-power state for 50% of the idle time. We have recently refined this work to calculate the percent of idle time in the low-power mode as a function of copier speed, copy volume, and the time required to enter the low-power mode after a copying job is completed. I prepared figures 3.3-3.5 to show in graphical form that the fractional time in energy saver mode is a strong function of the transition time. An energy saver for a 15-cpm copier that takes effect after one minute will be in use over 90% of the idle time, decreasing slightly as copying volume approaches 10,000 per month, as indicated in Figure 3.3. By contrast, an energy saver that is not invoked until 15 minutes will be in use for 70% of the time and one that waits until 45 minutes have past will only be in use an estimated 20% of the idle time. Nearly identical energy-saver performance is found at the same copying volumes for faster machines, as shown in Figures 4 and 5. As monthly copying volume grows for the faster machines, there is less time between jobs and less opportunity to drop into a low-power state.

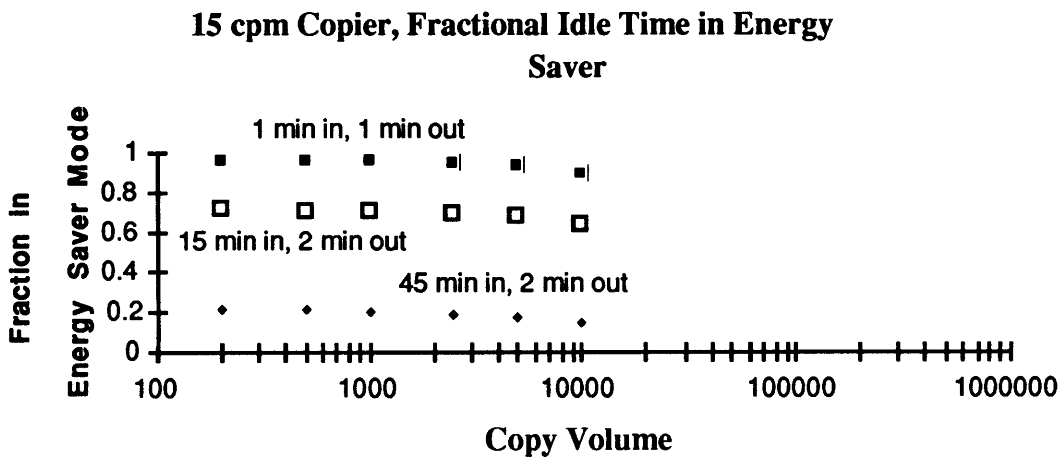

Figure 3.3. Estimated fraction of idle time in energy saver mode for a 15 cpm copier, as a function of monthly copying volume.

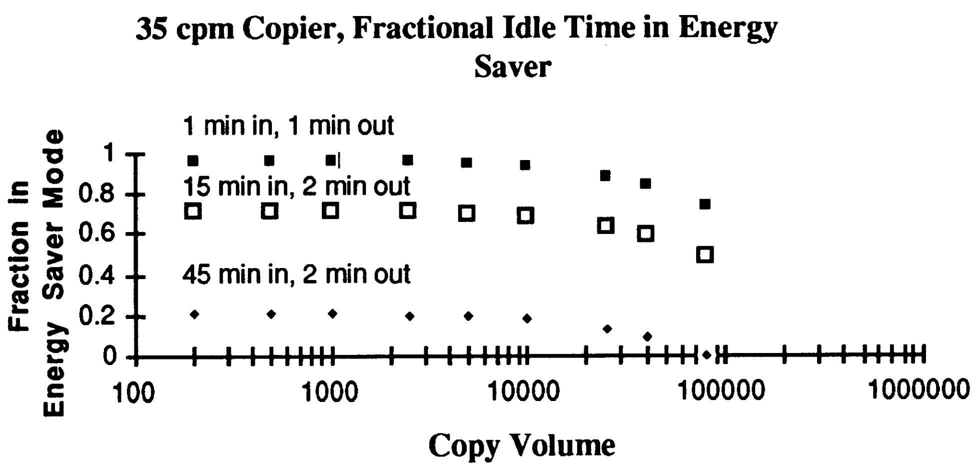

Figure 3.4. Estimated fraction of idle time in energy saver mode for a 30 cpm copier, as a function of monthly copying volume.

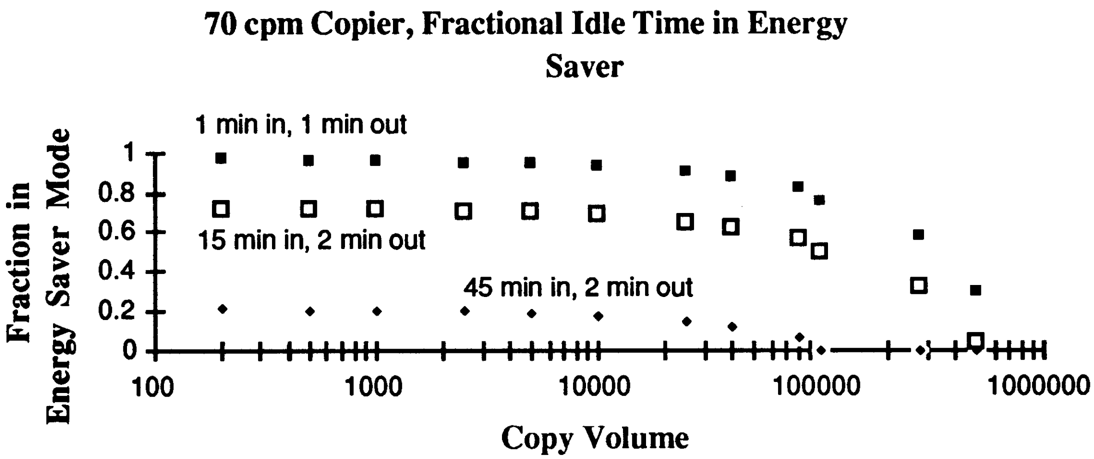

Figure 3.5. Estimated fraction of idle time in energy saver mode for a 30 cpm copier, as a function of monthly copying volume.

3. <u>Ink-Jet Copiers, Printers and Faxes</u>

Ink-jet copiers digitize the scanned image, rather than focusing the image to a photoconductor, and print a page by matching ink-cartridge nozzles to the electronic image. Ink-jet printers skip the scanning step, while faxes transmit the electronic image before printing (although a fax can function as a copier as well by printing a page rather than transmitting it to a receiving fax).

While ink-jet printing may be less energy intensive than laser printing, as we will see below, ink-jet printers do not match the speed of laser printers and only in high quality mode approach laser quality. Smearing is no longer a problem, even directly after a page is printed, unless the ink is first moistened and then rubbed. One manufacturer claims that once the ink is dry it is completely smear-proof. Printing speed is increasing for both ink-jet and laser/LED printers, with newly announced ink-jet printers reaching 7 pages per minute. Laser printers, however, have already reached 30 pages per minute. Ink-jet speed is limited by how fast the print head can move. One manufacturer confirmed that other design options are being investigated, including the possibility of using more than one print head, and a print head that would spray a line at a time onto the page.

Liquid-ink printing (ink-jet and bubble jet as examples) is an inherently low-energy process. Heat is required to vaporize the liquid ink, on a microscopic scale, in order to force it through the holes in the nozzles. Typically, heat is not required to fix the ink, which simply is absorbed by the fibers in the paper. However, the water-soluble ink tends to spread as it soaks into the paper, reducing the resolution that can be achieved. One manufacturer uses a fast-drying ink. Another manufacturer of a color ink-jet printer uses a heating element to dry the ink very rapidly, limiting the time for the ink to spread (Heid 1993). Ink-jet machines work optimally with a particular type of paper that inhibits the spread of the ink. However, for drafts of reports, ink-jets can easily reuse already image paper. The quality might be lower, but for drafts, this is generally not an issue.

Solid inks are also used in ink-jet color printers. The inks are melted from a solid to a liquid phase and sprayed through the nozzles onto the paper, where they solidify. The advantage here is that the inks are not water soluble and do not smear when wet. However, an energy penalty is associated with the phase change.

A liquid-ink printing process without the dryer establishes a lower bound for printing energy. As will be described in more detail later, we used available manufacturers' data and estimated printing energy for ink-jet printers and faxes to be 0.1 Wh/page. The comparable figure for a color ink-jet copier was higher, 1.6 Wh/page, but was based on manufacturers' specifications that may overestimate measurements. Heat-and-pressure printing required from 0.1-0.8 Wh/page, a large range. It appears that the best heat-and-pressure printing technologies require little more energy than ink-jet printing. One interpretation is that the transport energy in such cases is comparable and that the heating energy in heat-and-pressure printing is relatively small, given that the total printing energy for the two technologies can be essentially the same and that ink-jet printing at 0.1 Wh/page requires no heat. Another view is that small differences, on the order of 0.1 Wh/page, are of little concern when compared with the embodied energy in paper, nearly two orders of magnitude larger. As yet we have not obtained quantitative measurements of the extra energy required to dry liquid ink or to melt solid ink.

Ink-jet imaging equipment requires no heating during standby and ink-jet devices have no suspend mode. Power during standby has been measured at 2.5 Watts for a monochrome ink-jet printer and 7.8 Watts for a color ink-jet printer, compared to the 5 Watts achieved by only one monochrome laser printer in suspend mode. This particular laser printer is only a

4 page per minute laser printer, so it is not clear if the speed advantage of laser printers can be sustained with power management. This does indicate successful power-reduction engineering on behalf of the laser printer however, though it is important to remember that the laser printer will divide its idle time between standby and suspend modes and that its pattern of use will affect its overall energy usage.

4. Alternative Methods of Printing and Fixing Monochrome Images

Lovins and Heede (1990) discuss a number of methods for printing and fixing an image. None appear to better the energy performance of ink-jets, where the heat is applied in very small quantities and used only as needed. In contrast, heat-and-pressure fixing must heat the entire page during the fusing process and, more for copiers than printers, maintain the fusing unit at an elevated temperature when the machine is not in use. One alternative to heating the fusing unit, as noted by Lovins and Heede, involves radiatively heating the page and particularly the high-emissivity ink with a flash lamp. Fuser power is comparable to more conventional fusing unit heating. Standby power may be lower, because fusing unit temperature is not regulated. Test data for this and other technologies was not available to us at this time, but is needed to quantify the energy benefits.

Cold-pressure fixing, which Lovins and Heede note has been largely withdrawn from the market, relies on pressures so high that paper emerges with a glossy surface that is objectionable to some users and may reduce readability.

Ion-deposition imaging uses about the same pressure to fix a magnetic toner that is attracted to charge deposited by the printhead onto a very hard photocondutive drum that also serves as one of two rollers to fix the toner. Ion-deposition printing requires less power while fixing the toner but the photoconductor must be kept at 56-62 ^{o}C to reduce moisture levels and maintain its dielectric properties. The 30 and 45 cpm ion-deposition print engines are rated at 280 W in standby but this rating must be combined with a heater duty cycle to determine the average standby power and directly compare this technology with others. Nevertheless, the need for standby heat makes this technology less capable of low power in suspend mode than heat-and-pressure printing with low thermal-mass fusing rollers. The difference in power may be small for copiers, where short thermal recovery times are paramount, but will be larger for printers, where a longer thermal recovery time is acceptable. Importantly, ion-deposition printing is claimed to work well in duplexing mode.

Dot-matrix impact printers, while an old technology, still command significant market share. We have not determined a dot-matrix printer's energy consumption but note that a sample of these printers, according to Norford et al. (1990), required 11-20 W in standby and 23-46 W in operation. Both power levels exceed an ink-jet's requirements. These measurements show that less power is required to vaporize ink droplets, a thermal process, than is needed to transfer ink from a ribbon by physical impact. When heat or pressure is applied to an entire page and not just the ink or toner, pressure appears to require less power.

There are other thermal processes for printing and fixing images. Direct thermal printing involves a heated printhead that darkens thermally sensitive paper. In standby mode there is no need to maintain a heater at high temperature to fuse ink to paper. This technique is popular in entry-level fax machines. A major disadvantage of thermal fax machines is that thermal paper is sensitive to sunlight and will darken if exposed inadvertently to heat. Thermal fax pages are often copied onto plain paper, which could more than double the energy required to form a single usable faxed image on a page. The power required in standby by one thermal fax we evaluated was comparable to that needed by ink-jet fax machines and operating power for another model was also a match for ink-jet printing; no thermal fax machine used less energy per page than the ink-jet fax. Thermally, both apply heat where needed, at a very small scale.

In indirect thermal printing, heat activates a thermally sensitive sheet that transfers an image to plain paper. This type of thermal transfer is used in some faxes and also in two color printing technologies discussed below. According to Lovins and Heede (1990), thermal transfer requires more than double the printing power needed by direct thermal transfer.

5. Thermal-Wax and Dye-Sublimation Color Printing

Heid (1993) describes two other color printing technologies: thermal-wax and dye-sublimation. Thermal-wax printers use three or four color ribbons (cyan, magenta, yellow and often black), from which wax is melted and transferred to paper. As with ink-jet and heat-and-pressure color printing, a wide range of colors is obtained by dithering, in which adjacent pixels are colored in such as way as to appear to be a uniform hue. Dye-sublimation printers apply heat to solid dyes mounted on a ribbon to convert the dyes directly to the gaseous state, which is absorbed by polyester-coated paper. The dyes are transparent and color mixing can be accomplished by building up the three or four dyes at a single location on the paper, providing a more realistic output that is free of dot patterns.

We have no data for these technologies. A comparison among color printing is needed, both because the technology is becoming more important in the marketplace and because the data would highlight the energy required to heat not a fusing unit or an entire page (as is required with heat-and-pressure printing) but individual pixels of wax or dye.

B. Power Requirements and Energy Use

1. Copiers

Computers and displays were evaluated on the basis of power, in Watts, required by a piece of equipment when in three modes of operation: ready, standby and suspend. No attempt was made in general to estimate energy consumption over some period of time. The NRC data were used to indicate the fraction of the time that computers and displays are in use and these data could be applied to the computer and display power data to determine energy consumption.

The same distinction between power and energy holds for copiers, printers and faxes. This report presents energy consumption data for imaging equipment, normalized by the number of pages of output. The energy data are not meant to distract attention from the underlying technologies but to quantify their relative energy use and to illustrate the value of standardized energy calculation procedures. We have limited our calculations to imaging technologies not because the calculations are unimportant for computers and displays but because we have, as a parallel effort, taken the lead in preparing and revising the necessary test procedures for imaging equipment. The energy calculations are performed for a sample of representative machines that are or have recently been on the market.

Copiers will consume less energy if turned off when not in use for extended periods (overnight and weekends) and if they can switch from standby to a low-power energy saver or suspend mode. Several copiers listed below incorporate a suspend mode. Some of these copiers only go into a low power state if users press a key on the control panel. Control that is exclusively manual is almost certainly less effective than automatic switching, because users may not take advantage of the feature or may use it at night in lieu turning off the power.

Duplexing, or double-sided copying, is important because the energy consumed to produce paper is considerable. Unfortunately, Wirth (1992) states that copiers typically do not duplex well. Poor duplexing implies soiling of fuser rollers, wrinkling of paper, frequent jamming, and no allowance to eject copies after a job interrupt. In the case of automatic duplexing, a common feature on higher volume machines, the user can perform the task by means of a key press on the control panel. However, many low-volume copiers only permit manual duplexing, which means that the user must reinsert the paper. As can be expected, this is often deemed by the user too time consuming to be worth the effort. Furthermore, Buyers Laboratory (1992) rated many manual duplexers as being satisfactory, as opposed to good or above average, and some as being good only for small jobs.

Determining copier energy usage is difficult, because it depends on the combined impact of several modes of operation: a plugged-in machine that is turned off, warm-up, idle (with or without an energy-saving mode), and copying. It may be intuitively apparent that a certain approach to manufacturing a fuser roller should reduce the energy required to fuse the toner, but a quantitative measure of the impact of such a feature is needed. There is an ASTM test method (ASTM 1984) to determine copier energy use. It defines a method to measure energy use in plug-in, warm-up, stand-by and copying modes. It provides a job matrix, test conditions and a worksheet for manufacturers to fill out. Unfortunately, all manufacturers do not use these data when providing energy information to interested parties, and some have taken measurements that differ from ASTM data. For instance, Brown Vence and Associates (1991) reports power levels for one machine as 0 W plug-in, 230 W warm-up, and 67 W idle. The data collected through the ASTM method give power levels for the same machine as 1 W plug-in, 160 W warm-up, and 133 W idle. The differences are large and unpredictable. We have obtained ASTM test data from a state procurement office which requires the data as part of contract bids and from a single manufacturer which tests all of its copiers using the ASTM method.

The ASTM test procedure is out of date and needs to account for the probability that a copier will be left on over night, duplexing, and most importantly, those copiers that have an energy saver mode. We have used the method in Appendix A to calculate the Watt-hours per month and Watt-hours per page consumed by each copier. Our method is derived from the ASTM procedure and some of the modifications have formed the basis for a formal revision to the ASTM method, which is currently under ASTM committee review, and is included in Chapter 4. It should be noted that the revised method relies on assumed values for the length of a typical work day and the fraction of copiers left on at night. It also takes only the crudest account of an energy-saver mode, by crediting 50% of idle time to this low-power state. We simply lack the information about usage patterns and energy-saver controls to be more precise but will point out where appropriate the energy benefits of extending the energy-saver mode to cover all of the idle time. This does not match current practice but points toward a more powerful, user-adjustable energy-saver feature that can, if the user so chooses, be in effect whenever a copier is not in use. Practically, this means that a user could choose to wait a few seconds for the fusing process to be ready for the first page of a copying job, in exchange for an energy savings. We advocate controls that empower users in an office to make consensus decisions about productivity cost, if any, versus the energy benefits of shortening the trigger time for a copier to drop into energy-saver mode.

a. Heat and Pressure Copiers

Table 3.9 contains the information that we have used to calculate the energy values in Table 3.9. In both tables, there are three machines in each speed category. As discussed above, the data were difficult to obtain and collection methods differed. Data collected with the ASTM method were not available for two of the copiers. Print energy per page was not available for one. Also given in Table 3.9 are warm-up time and copier speed. When available, these numbers were taken from Buyers Laboratory, Inc., a testing service for imaging equipment that issues test results in the form of Buyers Guides. Buyers Laboratory's analysis of a machine's ability to duplex is also given in notes below the table; only one of the machines in Table 3.10 was rated good or very good in its ability to duplex. Energy data were available for duplexing for a single copier. The duplexed copies used 0.01Wh/page more when copying than the simplexed copies, a minuscule increase compared to the energy embodied in a sheet of paper. Table 3.10 includes total energy per page and highlights two of the constituents, energy for printing and idle modes, while suppressing plug-in and warm-up modes. The last factor is typically very small but, can be significant in some cases.

Table 3.9. Power Consumption for Heat and Pressure Copiers.

Speed (cpm)	Plug-in (Watts)	Warm-up (Watts)	Suspend (Watts)	Standby (Watts)	Printing (Watts)	Warm-up time (s)	Speed, w/ 1st copy (cpm)
< 15	0-25.3	27 - 157	n/a	69 - 140	1,500	60 - 71	9 - 15
15 - 35	0 - 7.0	160 - 189	49 - 106	133 - 148	n/a - 650	60 - 87	17 - 21
35 - 60	30 - 45	17 - 212	135 - 153	n/a - 163	1074-1700	180	33 - 48
> 60	0 - 59	367-1000	150 - 193	200 - 457.5	1300-2400	220-446	66 - 83

Notes:

1 None of the suspend or energy-saver values are from the ASTM test procedure, which does not acknowledge a suspend mode. The suspend-mode values given here were either estimated or taken from another source, preferably from measured data collected by Brown, Vence and Associates (1991).
2 The ASTM procedure requires printing energy for a specified number of copies; printing power was calculated from printing energy and copier speed. When ASTM data were not available, data provided by the manufacturer, Brown Vence and Associates (1991) or Competitek were used.
3 Duplexing capabilities range from automatic to manual, with the quality ranging from very good to satisfactory. Most of the higher volume copiers had automatic duplexers. The copiers that we looked at that had speeds of less than 15 cpm had only manual duplexing.
4 Most of the included machines have standby keys. All of the machines in the greater than 60 cpm category had standby keys, though they have to be programmed by a technician.
5 Occasionally copying speed and warm-up times were provided by manufacturer's specs, not Buyers Laboratory, Inc.
6 Manufacturer specifications for power levels were much higher than that provided by ASTM data.
Lovins and Heede (1990), which presumably gave measured data, and BVA often have power levels very different than ASTM measured data.
7 Occasionally, a manufacturer reported that a machine had no energy saver mode, but the specifications included power for the energy saver function. In this case, the specified value was used.
8 The energy level for a recirculating document handler may use as much as 8% more energy than the base copier (see discussion below).
9 There were three machines in each category.

Table 3.10: Copy Volume and Energy Use for Heat and Pressure Copiers.

Speed (cpm)	Monthly Copy Volume	Total kWh/month	Printing Wh/page	Idling Standby+Suspend Wh/page	Total Wh/page
< 15	4,000	17 - 48	0.2 - 1.3	3.8 - 7.9	4.2 - 12
15 - 35	10,000	28 - 50	0.8 - 1.4	2.0 - 3.3	2.8 - 5.0
35 - 60	40,000	82 - 93	0.4 - 0.7	0.8 - 1.6	2.1 - 2.3
> 60	100,000	119 -132	0.4 - 0.5	0.4 - 0.6	1.2 - 1.3

Total energy per page decreases for the faster machines because we assign to them a larger copying volume and standby energy is apportioned among a larger number of copies. At low volumes idle energy dominates print energy, while the two terms are nearly equal at large volumes. From the ASTM data provided by one of the machines evaluated, an automatic document handler would add 7-8% to the calculated energy consumption of the copier.

Copy volume strongly determines the benefit of a suspend mode, which trims the energy per page in idle. If the most efficient 60 cpm copier were installed in an office requiring only a 15-35 cpm copier, it would use 5.2 Wh/page in idle, 8.9 Wh/page total energy, and 89 kWh/month. However, if the copier were to go into an energy-saver mode immediately after a copy was made, the values would be lowered to 1.7 Wh/page idle, 5.3 Wh/page total, and 53 kWh/month.

Energy differences among comparable copiers are largest in the <15 cpm category. Calculated energy for the most efficient machine would have been even lower had we obtained a value for its energy-saver mode. Per-page printing energy is remarkably low, much smaller than would be predicted by the trend toward lower printing energies for faster machines.

One copier used considerably more energy, 5.0 Wh/page, than the other two machines in the 15-35 cpm class. Relative to the lowest figure, 2.8 Wh/page, this machine fared poorly in several modes: plug-in energy per page, was higher by 0.5 Wh; idle energy, while not the highest of the three machines, still exceeded that of the best machine by 0.81 Wh; and printing energy was 0.62 Wh larger. The contribution of plug-in energy stems from 13 W power draw while the machine is plugged in but turned off. The more efficient copier drew only one Watt in this condition.

b. Ink-Jet, Surface-Fusing, and Liquid Ink Copiers

Three different types of copiers are reviewed here: a color ink-jet copier, a small personal copier, and two liquid-ink copiers. The ink-jet copier is only good for small jobs, at a monthly volume of about 500 copies. It is noteworthy that a copier essentially consists of a scanning and printing mechanism and that this particular model can function separately as a scanner and printer if attached to a computer. Multi-purpose machines will be discussed later in this review.

The personal copier uses surface-fusing technology. It is also designed for small jobs, at a monthly volume of about 500 copies. The liquid-ink copiers were "recommended with reservations" by Buyers Laboratory, Inc., the lowest rating of any copier that we have included in this review. The copy quality is not as high as most copiers tested, but the consumable costs are much lower.

Energy use as presented in Table 3.11 was made by scaling the copy volume for the ink-jet and surface-fuser copiers, both <15 cpm machines, to 4000 copies per month, the same figure used for the heat-and-pressure copiers in the same class.

Table 3.11. Energy Use for Ink-Jet and Liquid Ink Copiers.

Speed (cpm)	Total kWh/Month	Printing Wh/page	Idling Standby+Suspend Wh/page	Total Wh/page
< 15	9.2 - 22.8	1.6 - 3.9	0.4 - 0.9	2.3 - 5.7
15 - 35	59	0.9	4.8	5.9
35 - 60	68	0.5	1.2	1.7

Notes:

1 Power levels for the personal copier and the ink-jet copier were given by the manufacturer.

2 Warm-up power for the ink-jet copier was not provided; an estimated value of 30 W is used.

[3] The power levels for the liquid ink copiers were collected using the ASTM method.
[4]Speed is measured with the first copy.

Because we calculated energy consumption for the ink-jet and surface-fusing copiers on the basis of manufacturers' specifications rather than unavailable ASTM data, comparisons with the heat-and- pressure copiers documented in Table 3.10 should not be taken too far. The manufacturer's ratings for the ink-jet copier are such that we calculate it requires more printing energy than the heat-and-pressure copiers, which is not consistent with the printing technologies. The ink-jet copier uses very little energy while idle and, even with what appears to be an artificially high value for printing energy, its total energy use of 2.3 Wh/page is easily the lowest of any copier of its size. The idle energy/page for the surface-fusing copier is much lower than for conventional heat-and-pressure copiers that maintain higher fusing roller temperatures. It is interesting to note that the 15-35 cpm liquid-ink copier used *more* energy in idle and in total than heat-and-pressure copiers in the same class while the faster liquid-ink machine used *less* than its heat-and-pressure competitors.

2. Printers

Printers embody technologies similar to those used on copiers and faxes. Printers as well as copiers benefit from a suspend or energy saver mode to reduce standby power. As with copiers, printer speed is tested in the as-shipped configuration. Because it takes the rollers time to warm up from the suspend mode, manufacturers usually ship the printer with the mode disabled. Duplexing, or double-sided reproduction, is also an important aspect of printing. Unfortunately, according to Buyers Laboratory, Inc. (1992), automatic duplexing is not common in printers and does not work well. Printers often have a manual feed slot which could be used to manually duplex. This takes extra effort on the part of the user and presumably it is rarely done.

Methods for measuring printer energy consumption are not yet standardized. There is currently an ASTM test method for printers now under review by the ASTM F05 committee. It is included in Chapter 4. Such a method is needed to define the energy use of the different modes of printers: plug-in, warm-up, standby, suspend, and printing. For this test method, a job matrix was defined to specify the number of print jobs per day and the number of pages printed for each. In addition, the length of a typical workday, the fraction of machines left on overnight, and the hours per day that machines could be in suspend mode were estimated. We first developed the method in Appendix B, based on ASTM F757, to calculate the Watt-hours per month that are used by the printers we have reviewed. This procedure has been subsequently refined and will be submitted for ASTM review. Chapter 4 and 5 will talk about the ASTM procedures in more detail.

Table 3.12. Power Consumption for Printers

	Standby (W)		Printing (W)		Suspend (W)	
	Manufact.	Huser[1]	Manufact.	Huser[1]	Manufact.	Huser[1]
Ink-Jet 3 ppm	2.5 - 7.9[2]	8.6 -11.8	13.0 -13.2[2]	15 - 23		
Laser 4 ppm	36 - 43[3]	44 - 53	113 - 130[3]	137 - 216	n/a - 7.0[3]	
Laser 8 ppm	49 - 70 [3]	76 - 98	169 - 213[3]	247 - 280	n/a -18[3]	
A-Si LED 10 ppm	110[3]		370[3]			
Laser 15 ppm		145		450		

n/a = data not available.
Notes:

[1] Huser et al. (1992).
[2] Measured data.
[3] Data from manufacturer's specifications.

Table 3.12 contains the information used to calculate the energy values in Table 3.13. Power data were difficult to obtain at best and Table 3.12 is unfortunately missing information. No data were available on plug-in power, which would add to the totals in Table 3.13. Data were obtained from manufacturers, supplemented by our measurements, and from measurements reported by Huser et al. (1992). For each class of printer, Huser's data are typically for older models than are manufacturers' specifications. Printing speed and monthly volumes used in calculations summarized in Table 3.12 were taken from Buyers Laboratory information. Comparisons among the manufacturer's data should be made with reservation, given the lack of standard data collection.

Ink-jets use much less energy than laser printers and the A-Si LED printer, for equal monthly printing volumes. Measurements show that a monochrome ink-jet printer draws only 2.5 W in standby and 13.0 W while printing, while a model that can also print in color draws 7.8 and 13.2 W in standby and printing. The speed drops when printing in color, so the energy values are raised to 2 Wh/page. The A-Si LED printer uses only slightly less energy than laser printers of comparable speed.

Table 3.13. Energy used by Printers. (Monthly printing volume of 1000 pages per month)

	Total kWh/Month		Idling Wh/page		Printing Wh/page		Total Wh/page	
	Manuf.	Huser	Manuf.	Huser	Manuf.	Huser	Manuf.	Huser
Ink-Jet 3 ppm	0.6-1.8	1.9-2.7	0.5-1.7	1.9-2.6	0.1	0.1-0.15	0.6-1.8	1.9-2.7
Laser 4 ppm	5.6 -8.7	11 -12	5.1-8.1	10 - 11	0.5	0.6 - 0.8	6.2-8.7	11-12
Laser 8 ppm	8.0 - 16	18 - 23	7.7 - 16	17 - 22	0.3-0.4	0.55-0.6	8.0-16	18 - 23
A-Si LED 10 ppm	26		24.7		0.6		26	
Laser 15 ppm		35		33		0.5		35

In general, manufacturers' power requirement specifications for most office equipment are higher than measured data. This is not the case for printers. While measurement methods may differ, we consider the primary reason to be that Huser measured machines with older technology. Trends show that as newer technology emerges, the power usage for comparable machines goes down. For instance, one older version of a color ink jet printer used 9 W in standby, and 15.8 W when printing. The newer version, which uses two cartridges instead of one, used 7.8 W in standby and 13.2 W when printing. The electronics in this machine use the more efficient CMOS technology.

Energy per page is determined almost exclusively by the apportionment of standby energy to the monthly volume of printed pages. Buyers who select a high-speed printer for a low-volume office where a low-speed printer is satisfactory are penalized in terms of per-page energy use. Conversely, when energy per page is calculated for higher volumes, the values drop significantly. For instance, when using a volume of 5000 copies per month, the A-Si and the 15 ppm laser printer drop down to 5 Wh/page and 7 Wh/page, respectively.

Reduced power while a printer is idle is important. Our calculations are based on 50% of idle time in a suspend mode, if present. One 8 ppm laser printer uses roughly the same amount of energy as a 4 ppm printer, for the same monthly volume, because the faster printer features a suspend mode and a low idling power consumption. If the faster printer did not have the suspend mode, energy consumption would increase from 8 to 12 Wh/page. The values are still less than the other 8 ppm laser printers, because the standby energy is low, but the advantage of an energy-saver mode is obvious. Conversely, if the printer were put immediately into a suspend mode after each use, it would use only 4.5 Wh/page, a value which is lower than the most efficient 4 ppm laser printer. Similar patterns can be seen with a 4 ppm printer that has an energy saver mode. If its suspend mode were turned off, per-page energy consumption would be 9 Wh/page rather than 6.2; if it went into the suspend mode immediately, the value would drop to 2 Wh/page. Even though ink-jets usually offer much lower energy consumption than laser printers because their standby energy is lower, that advantage is minimized if the suspend mode on a laser printer is invoked immediately.

3. Faxes

Unlike other types of equipment, faxes must be powered continually, in order to receive incoming messages. There is little information about the duty cycle of faxes. The National Research Council of Canada is currently conducting, at the level of a small survey, a review of the printed logs that faxes produce of incoming messages. More globally, thermal fax usage in total, without regard to time-of-day distribution, could be estimated from fax and thermal paper sales. Huser (1991) suggests an average duty cycle of 100 pages per day for both transmission and reception. For transmission and reception times of about 13 seconds , this operating schedule keeps the fax in use for 43 minutes per day, or three percent of the time. We will bound energy consumption by factors of three above and below Huser's estimate: nine percent operation as an upper limit and one percent at the lower end. The predominance of time in standby suggests that once again standby power and opportunities for power management will strongly influence energy consumption. The different types of fax technologies will be distinguished by their use of paper as well as direct energy, and the energy embodied in paper utilized.

a. Direct thermal faxes

Huser reports an average measured standby power of 12 Watts for 51 direct-thermal fax machines, with a standard deviation of 4 W. Manufacturers' specification sheets that we obtained for four machines listed standby powers of 12, 18, 30 and 65 W. We caution against comparisons with these numbers, which may or may not be measured.

Huser, for the same set of 51 machines, lists per page energy use of 0.57 Wh for transmission (standard deviation of .34), a slightly higher value of 0.69 Wh for reception and printing (standard deviation of .3), and 0.3 Wh for printing alone, which yields an operating power, averaged over transmission and reception/printing of 177 W. Operating powers that we obtained from specification sheets were 26, 120, 180 and 230 W. Energy consumption per page increases dramatically when standby energy is included, as shown in Table 3.2.14. Here energy values are calculated for two machines: a composite fax derived from Huser's measurements and one with manufacturer's ratings of 18 W standby/ 25 W operation. Note that the choice of the first two machines, on the basis of energy consumption, varies with the assumed duty cycle.

Table 3.14. Energy Consumption for Thermal Faxes

Standby/ Operating (W)	Total kWh/month			Operating Wh/page			Standby Wh/page			Total Wh/page		
	Pages/day			Pages/day			Pages/day			Pages/day		
	67	200	600	67	200	600	67	200	600	67	200	600
12 177	9.0	10	14	0.6	0.6	0.6	6.0	2.0	0.6	6.6	2.6	1.2
18 25	13	13	13	0.1	0.1	0.1	9.0	2.9	0.9	9.1	3.0	1.0

The dominant role of standby energy at lower duty cycles prompts a closer look at the end-use power disaggregation during standby. Miteff and Winter (1991) have taken data that show 95 percent of a total standby power of 8.8 W going to the modem and the remainder distributed among sensors and controls. A total of 9 W does not support expensive design changes to achieve power management, but there may be low-cost opportunities. Modems within portable computers operate at much lower powers and the computer and modem can assume a very low power standby mode even while remaining alert to incoming communications signals. One fax/modem, intended for use with a personal computer as an external unit with its own power supply, uses only 4 W while another, with memory for up to 60 pages, uses 4.5 W.

b. Ink-jet faxes

An ink-jet fax, made by a single manufacturer and sold under several brand names, has a standby power of 13 W, 25 W for transmission and 23 W for receiving documents. This machine offers energy performance that matches the best thermal faxes by combining very low standby and operating powers. In addition, it produces high quality images on plain paper, in contrast with the well known limitations of thermal fax paper. Further, an ink-jet fax will accept paper that has already been printed on one side, reducing the cost and embodied energy associated with the paper. Table 3.15 presents the energy use per page and per month under the same 200-page-per-day duty cycle assumed for thermal faxes.

Table 3.15. Energy Consumption for Ink-Jet Fax.

Standby/ Operating (W)	Total kWh/month	Operating Wh/page	Standby Wh/page	Total Wh/page
13 24	10	0.1	2.1	2.2

c. Front-end to laser printers

Many offices are equipped with laser printers. Newly available fax attachments make use of the laser-printer engine in a way that offers a number of advantages relative to other fax technologies. The fax can be networked much as a printer, making it possible to send faxes from a computer without first printing and then scanning within the fax. In fact, some fax front ends lack a scanner. Incoming faxes at night can be stored within the fax machine, with the laser printer powered down, and printed the next morning. One model can store in memory the equivalent of 75 pages. The *standby* energy ascribed to the fax is simply that of the fax itself, with no penalty for a printer that is operating normally during the day and is off during unoccupied periods. By contrast, *operating* energy for reception and printing must include the energy use of the laser printer. We measured 16 W in standby for a fax front-end that included a scanner, and 25 W operating power while transmitting, thus it is comparable in these modes to the ink-jet fax. Assuming all outgoing faxes are sent from a computer and that incoming faxes are printed at 0.4 Wh/page, the 200-page-per-day duty cycle yields a total energy of 2.8 Wh/page, all but 0.1 Wh/page in standby.

d. Fax cards

Fax cards installed within a computer eliminate the need to first print a document and then fax it. While it is possible to scan a page with a dedicated scanner and then fax it from a fax card, we suspect that few would choose this option in lieu of a separate fax in addition to a fax card. One manufacturer reported its fax card as using 0.7 W active and less than 5 mW inactive. Since the card does not have a power supply built in, a factor of 0.6 should be added to the values to account for the inefficiency of the power supply. Still, that only brings the power draw up to 1.2 W and 5.3 mW respectively. Reception energy will depend on whether the document is printed or simply retained in electronic form. Standby energy is negligible when the computer is otherwise in use but can be relatively large when a computer is kept running solely to receive a fax. The fax card therefore has more appeal when installed in computers with power management, as indicated in Table 3.16. With this feature, a fax card offers the best energy performance; without it, this technology trails ink-jets, direct-thermal faxes, and most laser faxes.

Table 3.16. Energy Consumption for a Hypothetical Fax Card

Standby/ Operating (W)	Total kWh/month	Operating Wh/page	Standby Wh/page	Total Wh/page
2 500	7.0	0.2	0.2	0.4
31 500	28	0.2	3.3	3.5
76 500	60	0.2	8.1	8.3

Assumptions:

1. 1 W attributed to the fax.
2. Computer standby power of 1, 30 and 75 Watts, applied to night (12 hours) and weekends.
3. Laser printer energy of 0.4 Wh per page, applied to half of the received pages. Laser printer not running at night and on weekends, with incoming faxes stored in computer.

e. Laser and LED faxes

Laser faxes use the same printer engine, toner-fusing technology and plain paper as laser printers. Standby power, needed to keep the fuser unit warm, exceeds that of direct-thermal and ink-jet faxes. Huser reports an average standby power of 62 Watts, for a sample of five. Huser's sample required, on average, 1.6 Wh for transmitting a page and 2.4 Wh for reception and printing, with the increase due to fusing toner to the page. The average energy of 2.0 Wh for transmission and reception, at 7 pages per minute, yields an operating power of 840 W. We found a machine that, according to manufacturer's data, required only 20 Watts in standby, 0.12 Wh to transmit a page and 1.5 Wh to receive and print, at 7 pages per minute. Two other machines fell between these bounds.

To compare the energy use of laser faxes with direct-thermal and ink-jet machines, we will use the same number of pages per day. Operating time for the laser faxes is shorter and standby slightly higher, due to the faster transmission/reception speeds. In Table 3.17 we compare Huser's average machine with three models for which we obtained manufacturers' data. Each of the three machines require considerably less energy than the average of Huser's five machines. Total energy is most strongly affected by standby power, where the values of 20, 25 and 30 W shown in the table exceed by roughly a factor of two the best thermal fax standby power of 12 W. That is, the laser faxes in standby use twice (or more) as much power as is required for the modem. At low duty cycles, the large operating power required by laser faxes is a small contributor to the total, and laser faxes compete better than we expected with thermal faxes: 4.1 Wh/page for the best laser fax compared with 2.6-3.0 Wh/page for thermal faxes.

LED faxes are very similar to laser faxes, with both relying on a combination of heat and pressure to fuse toner to the printed page. The LED fax employs an array of light-emitting diodes rather than a laser and mirrors to create the image to be printed. We expect energy consumption to be nearly identical. Table 3.17 also presents data for the LED fax made by one manufacturer and marketed under several brand names.

Table 3.17. Energy Consumption for Laser and LED Faxes

Laser Standby/ Operating (W)	Total kWh/month	Operating Wh/page	Standby Wh/page	Total Wh/page
65 840[1]	55	2.0	10.8	12.8
20 340	18	0.8	3.3	4.1
30 960	31	2.3	4.9	7.2
25 58	19	0.13	4.2	4.3
LED 30 58	22	0.1	5.0	5.1

1. Average of five machines.

f. Summary

The energy per page required to operate a fax does not include the energy embodied in the paper. Because the embodied energy of 10-20 Wh/page exceeds most of the calculated operating energy values presented in the previous tables, it is important to distinguish fax technologies by their use of paper. Table 3.18 characterizes faxes by total energy per page, the type of required paper, and capability to transmit or receive faxes without printing.

Table 3.18. Summary of Fax Features and Performance

Type	Total energy[1] Wh/page (200 ppd)	Paper	Transmit/receive w/o print
thermal	2.6 - 3.0	thermal	
ink jet	2.2	plain	
front end to printer	2.8	plain	transmit
fax card	0.4 - 8.3	separate printer	transmit/receive
laser	4.1 - 12.8	plain	
LED	5.1	plain	

Note:

[1]This does not include the energy attributed to the paper.

A direct-thermal fax uses more energy attributed to the paper than other types of fax machines, because the thermal paper is more energy intensive than plain paper and because incoming faxes are often recopied onto plain paper. An ink-jet or laser fax, because it prints on plain paper, may be able to receive faxes on reused as well as fresh paper. A fax attached to a laser printer, like a separate laser or ink-jet fax, can be charged with embodied paper energy ranging from 0 to 100 percent for both transmission and reception. Its ability to send faxes directly from a computer, without the intermediate step of printing, makes it somewhat more likely that the average embodied energy for transmitted images will be lower. However, the fax front-end to a laser printer and a laser fax may not be able to reliably run on reused paper for incoming faxes, due to jamming within the printer. Finally, a fax card can only send electronic images, with no embodied energy, absent the use of a separate scanner.

VI. Combined Devices, Multimedia and Networking

A. Combined Devices

Combined devices connect many different components and put them in one machine. There are several such machines on the market now, including the ink-jet copier discussed above that can separately scan and print; an all-in-one combination of personal computer, copier, scanner, laser printer, modem and fax machine; the same combination without the computer; a fax, personal computer and scanner; and a portable computer and ink-jet printer. With a combined device, only one machine would be powered on, in lieu of as many as five or six. In addition, a fax can be transmitted without printing. However, standby energies may be high. The all-in-one machine that does not include a computer will not function at all unless an attached computer is on, since all the necessary circuitry resides on the expansion board that is installed in the computer. The energy savings from these types of machine may vary; if the machine can be power managed or paper use can be reduced, the savings would be considerable.

The savings from these devices are not only in energy; they may cost considerably less money than if all the components were bought separately and they require less space in an office. One machine that combines five components costs $4,000, versus about $12,000 if they were purchased separately.

1. Ubiquitous Computing

Emerging electronic notebooks and personal digital assistants may create a new market for computing devices. Some early versions of this type of equipment permit auto rental company employees or meter readers to work more efficiently. They could be joined by electronic displays mounted on shopping carts, auto dashboards or even wrists. The power implications are uncertain due to a lack of forecast information about market. Data about power requirements per unit are also scarce, but it is reasonable to assume that most will demand about the same amount of power as a modest laptop computer.

2. More Input/Output: Multimedia

Multimedia systems, whether based on computers or television, manipulate audio and moving video information. Increasingly familiar applications of PC-based multimedia include college-classroom education packages that feature videos and interactive electronic books for children. More exotic at the moment are electronic mail with videos clips, news reports for desktop computers, and electronic meeting rooms that permit presentation, exchange and recording of information. Electronic desktop video-conferencing and electronic publishing are being introduced (Reinhardt 1993). Information packets, pictures and video clips, as well as magazines, journals and books are being published at the desktop level. Manufacturers are developing tools to makes time-sequenced video and audio information as easy to manipulate and include in documents as text (Adam 1993.) Multimedia employs digital signal processors, stereo speakers, compact-disk ROM (CD-ROM), video cameras and large amounts of data storage. Data may be compressed before transmission and must be decompressed by the recipient. Because the density at which data can be stored is increasing, there is little or no energy penalty associated with the storage. Since less paper may be used with such forms of data storage, embodied energy of paper may be reduced. The peripherals need to receive the same attention to power management as the computer itself. Computer power under peak operating conditions will increase, because the digital signal processors are designed to relieve the CPU of the burden of data compression and decompression, allowing the CPU to perform other tasks in parallel.

Fast transfer of the enormous amount of data associated with digitized images requires more than data compression algorithms implemented in specialized video processors. In addition, it demands very large bandwidths for the data bus within the computer and for I/O devices (Cole 1993). Multimedia's demand for wider data buses and faster data processing will make obsolete many existing personal computer architectures. The technological push from multimedia offers an opportunity to build into new devices and computer architectures the necessary features for effective power management.

3. Networking and Telecommunications

Downsizing of computers is an established trend that has been fueled by the price/performance ratios of workstations and personal computers. Networked clusters of the smaller machines can for many applications substitute for a single mainframe. Networking demands additional communications equipment, either hard-wired or wireless. As will be discussed in the power management section, it also places more stringent demands on power management hardware and software. Computers in a low-power state must awake to respond to a communications signal while, ideally, keeping as much of the machine as possible inactive.

Beyond the confines of the local network, telecommunications through integrated-services digital network (ISDN) telephone service or cable TV. Either cable TV or the coaxial cable or fiber optics used for ISDN remove the data bottleneck of low-speed copper wire used for telephone service. ISDN connections for computers are available on plug-in cards; as a portent of the future, one manufacturer includes a ISDN connection as a standard workstation feature.

Wireless communication takes many forms: pagers, wireless telephones and wireless personal communications services (PCS). PCS provides radio communication (at microwave frequencies) to portable receivers. The ultimate goal is voice and data communication to handheld receivers identified by a single number, eliminating the multitude of numbers now in use at home, work, car, pager and fax (Kobb 1993). Examples of PCS today include personal communications networks (PCNs) that work over metropolitan areas, public cordless pay telephone services under trial use in England, Singapore, Australia and Hong Kong, and PCS services owned and operated by users within their own buildings, such as wireless local-area networks (LANs). Wireless LANs eliminate installation of communications wiring for desktop computers, which is particularly expensive in existing buildings. They also provide a communications base for handheld information devices. Kobb points out that applications include shared notetaking on college campuses (which he labels "virtual whiteboard") and mobile data entry.

We have yet to quantify the energy implications of shared network services. Fischetti (1993) states that handheld cellular telephones radiate about 0.6 W of power, comparable to a flashlight battery. The FCC sets limits above which radiation testing is required to determine human exposure to radiated energy, which is in the microwave region of the electromagnetic spectrum. Limits decrease with increasing frequency. For telephones, the limit is 0.74 W. Antennas for mobile car telephones radiate more power, 3 W. PCS telephones will use a higher frequency than cellular telephones and therefore be limited to lower power. One manufacturer claims 0.2-0.3 W.

From the perspective of energy use, these power levels are quite small. The market for microwave products is expected to explode within five years. For example, PDAs will send and receive messages, data and faxes on cellular networks. Despite large numbers of devices, the low power for communications and the diversity of usage (personal communications devices are typically idle) suggest that the total power required for communication may be reasonably small.

VII. Power Supplies

Power supplies used with computers are known for fairly low a/c to d/c conversion efficiency and poor power quality. Manufacturers must consider cost when specifying power supplies but the potential gain in efficiency and power quality at a modest increase in cost warrants a closer look at the subject.

Typically, the efficiency of power supplies used in desktop equipment does not exceed 70%; this figure may be lower for portable equipment. Two of the most interesting power quality parameters are power factor and total harmonic distortion (THD). Power factor is the cosine of the phase angle between voltage supplied to a piece of equipment and the current it draws. Resistance heaters have a power factor of 1.0, minimizing the current which must be supplied to provide a given amount of electrical power. Office equipment power supplies have power factors of 0.4-0.6, according to one developer of advanced power supplies and power-quality correction devices (Diablo 1992). For a given amount of power, a power supply with a power factor of 0.5 must draw twice as much current as a linear load, increasing heat dissipation in electrical wiring possibly on both sides of the utility' meter. Harmonic distortion measures the departure from pure sinusoidal waveforms; this can be measured at each harmonic of the fundamental and summed to arrive at THD. Distortion can affect the operation of some electrical equipment. Typical power supplies have THDs in excess of 100%.

Problems are created with the power supplied to office equipment if the electromagnetic characteristics such as immunity and emission limits are not compatible with the characteristics of the power system. If equipment does not have immunity to disturbances in the power system, harm to the equipment may result. However, if the equipment introduces disturbances to the system (emissions), poor power quality of the whole network may result (PQTN 1993).

Expansion cards are troublesome for reasons other than lack of standardized power management. Today, computer manufacturers may allow 25 W for each expansion slot (Bray 1993). The power supply must be sized accordingly, but will run at lower efficiency if the slot is unused. Bray claims that the efficiency of a power supply drops from about 80% at full load to 50% at half load. One manufacturer (Advanced Logic Research, Inc.) states that its 200 W power supply can idle at 30 W.

Linear dissipative and switch-mode power supplies are being used now for PCs. Linear dissipative power supplies are six times larger and three to six times heavier than switch mode power supplies. The switch-mode supplies have a high efficiency, from 65% to 95%, and consume less power than the linear supplies. However, they have a low power factor, and high harmonic currents.

Improved power supplies offer 85% efficiency, true power factor in excess of 0.95 and THD less than 10% (Diablo 1992) , for an additional cost of about $20. Add-on devices for existing equipment can correct power quality problems to the same extent but do not improve efficiency. The cost-effectiveness of such a power supply depends on power levels and hours of operation. A computer display drawing 75 Watts with a 70%-efficient power supply will need only 62 Watts if the power supply efficiency rises to 85%. If the display operates 2500 hours per year, with electricity priced at $0.10 per kWh, the power supply upgrade will save about $3.30 per year, leading to a 6.0 year simple payback period. The savings will drop if the display is power managed and drops to standby and suspend modes. If the display were in active use for about 30% of the time, as NRC's data suggest, and went to a 13 Watt standby mode for the remaining time without reaching the suspend mode, the better power supply would save $1.40 per year. Of course, there could also be savings in demand charges and air conditioning costs. It is not the intent of this technology assessment to provide detailed economic calculations; rather, it is worth noting that for power supplies as for LCD displays, efficiency improvements may have a noticeable price.

VIII. Conclusion

Electrical power for office equipment when operating is affected both by care in equipment design and by the underlying technology, such as LCD displays and ink-jet printing. Because most office equipment operates under low duty cycles, careful attention to reducing electrical power while equipment is idling is warranted. Spurred by EPA's Energy Star program, low-power design and power management have begun to appear in desktop computers. Portable computers offer increasingly effective power management, enhanced by CPUs with built-in control of peripherals that can respond to power-management signals. Suspend modes for portable computers appear to draw as little as one percent of operating power. More energy-efficient design and better power management could mitigate trends toward more powerful microprocessors with larger electrical power requirements, larger displays, and more widespread use of computers.

Issues associated with user productivity and reliability still need to be addressed. While a study has been performed on cycling and reliability issues associated with monitors and copiers (Miteff 1991), there have been none performed for fax machines, personal computers, or printers. Also associated with energy efficiency and lower energy use is the productivity issue. Copiers with low energy-saver modes often have a long wait time from the energy-saver mode to the standby mode. Ink-jet printing, which is more energy efficient than laser printing, tends to be slower and to have a lower quality.

Today, desktop computers rely nearly exclusively on CRT displays. Portable computers use LCD, plasma or EL flat-panel displays. Color displays are increasingly popular; among flat panels, LCDs alone have garnered the bulk of industrial support and proved able to produce a full range of color. Color CRTs currently enjoy a 5:1 cost advantage over color LCDs, which can operate with lower luminances and, based on scant data, about one-third less area-normalized power. Because CRTs appear to have a strong future, their response to a power-management signal during periods of computer inactivity becomes important. Both CRTs and LCDs can be switched to a low-power suspend state that requires so little electricity as to be considered nearly a *no*-power state, although CRT recovery time may be as long as 30 seconds.

There is a large range in energy consumption among copiers that fuse toner to paper through a combination of heat-and-pressure. For low speed (< 15 cpm) and low copying volume, energy per page varies by a factor of 3. For faster, 15-35 cpm machines, there is a 30 percent variation in energy per page, while at even higher speeds the differences among machines are vanishingly small. A low-speed ink-jet copier uses about half as much energy per page as the best heat-and-pressure machine. Similarly, ink-jet printers run at lower standby and operating power than laser printers. Their advantage is minimized to the extent that laser printers can quickly go to a low-power energy-saver or suspend mode when idling. Printers incorporate more effective suspend modes than copiers, perhaps because printers have time to recover while a page is being formatted while copiers are expected to respond very rapidly. User adjustment of the suspend mode for copiers is recommended, with office workers given enough information to trade off the time to heat the fuser unit against reduced operating costs.

Power Demand for State of the Art Office Technology

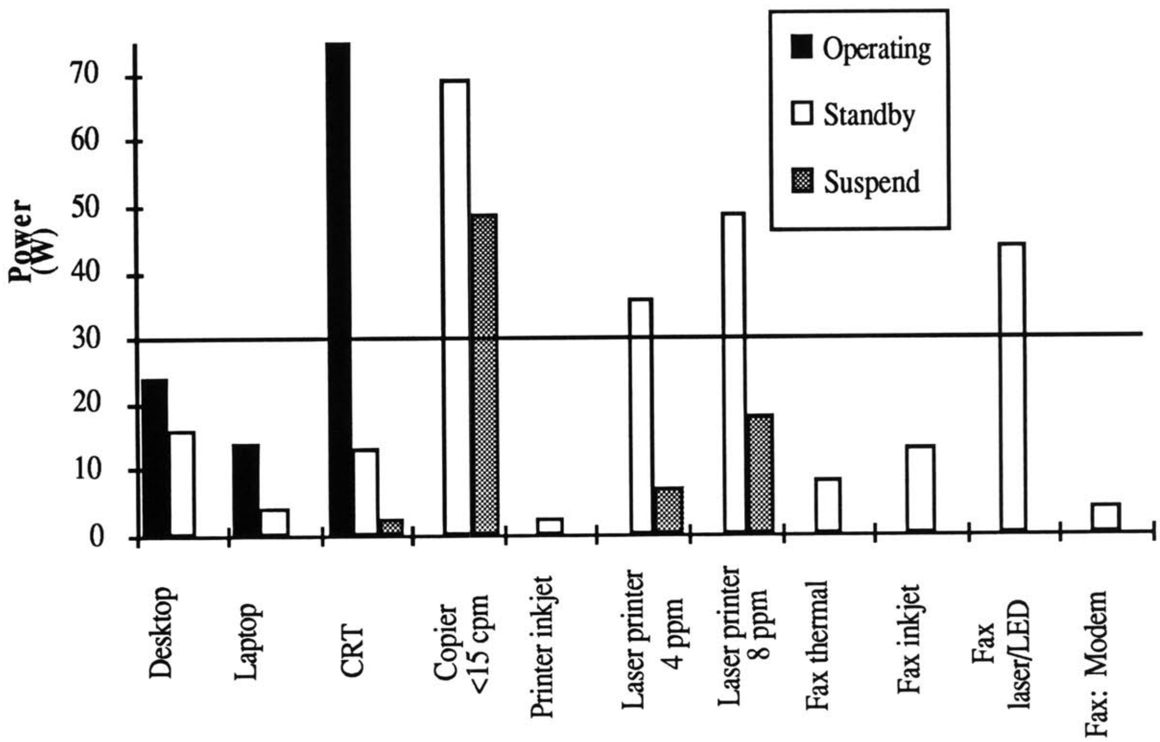

Figure 3.6. Power Demand for State-of-the-Art-Office Technology.

The very common direct-thermal fax suffers on average by comparison with nearly all other fax technologies. The energy use per page of the most efficient model we evaluated slightly exceeds that of ink-jet faxes, which offer significant opportunity to reduce paper use and, indirectly, the energy embodied in the paper. Laser faxes require about 50% more energy per page than thermal faxes. Fax cards installed in computers that have a low-power standby mode may offer the best energy performance.

To highlight the impact of power management and technology choices, Figure 3.6 illustrates powers for operating, standby and sleep modes. The desktop computer shown is power managed. The laptop, CRT, copier, 4 ppm laser printer, and the fax modem use a total of 58 W when machines are power-managed and 201 W when idle but not power managed, saving 71%. The power-managed desktop computer, CRT, copier, 8 ppm printer and a laser fax would use 130 W when machines are in a power managed state and 241 when not, saving 46%. Ink-jet printers and faxes offer substantially lower standby powers than their laser counterparts; the ink-jet and direct-thermal faxes are essentially equal. The increase power required by an ink-jet fax relative to an ink-jet printer may be due to the modem used in the former.

Chapter 4: Test Procedures for Measuring Energy Consumption of Office Equipment

I. Introduction.

Test procedures for measuring the energy consumption of office equipment are needed for providing information on energy use to consumers and for providing accurate methods of measurement for some of the programs that have recently emerged. As discussed in Chapters 1 and 2, the EPA's Energy Star Program specifies the power level a device must meet or beat. However, it does not provide manufacturers with a definitive way of measuring the power consumption of the device. I wrote several test procedures that are designed to provide users with a standard procedure that measures not only the average power of a machine in each of several modes, but also the energy consumption of the machine. I designed them in such a way to eliminate as much uncertainty as possible.

The measurements of each of five modes, plug-in, warm-up, stand-by, energy-saver and copying, are given in Wh, but are measured over an hour period. Therefore, since a watt-hour per hour is the average power over an hour period, the particular energy measurements can also be used to determine the average power requirements of each mode. The results can be used as a definitive way of measuring power consumption of a device, as is needed by the EPA's Energy Star program. The test procedures are also under consideration by the COPEE committee mentioned in Chapter 2 for use in their testing and information program. For this committee, the procedures can be used to determine a variety of information that is needed by office equipment users, by giving average power, or energy over a one hour period, a one month period, or a year. These values can lead to determining the average dollar per kilowatt needed per year, or even lead to the amount of carbon dioxide given off or power plants needed to run the machines.

The ASTM test method F 757 "Standard Test Method for Determining Energy Consumption of Copier and Copier-Duplicating Equipment" written in 1982, with editorial revisions in 1987, is an existing procedure for determining the energy use of copiers. I worked with the responsible ASTM committee to modify this procedure to better account for the way copiers are used, including a low-power energy saver modes (which would be termed suspend mode when describing power management in computers or displays), double-sided copying or duplexing, and longer hours of operation. The revised procedure, which is still under consideration by the ASTM committee, is included in section II.E. I wrote ASTM test procedures for printers and fax machines which are included in sections III and IV. I also wrote a computer test procedure, not under the ASTM committee. This procedure is in section V. In order to guide the copier, printer and fax procedures through the ASTM imaging committee, I became a member in 1992. I have attended three meeting per year, and wrote draft procedures before and after each meeting, in order to speed up the revision process. Summaries of each revision are included in this chapter.

The revised copier test procedure as well as the proposed printer, fax and computer test procedures rely on measured energy consumption taken over a one-hour period in each of several operating modes and estimates of the amount of time that a machine spends in each mode. The required calculations produce two figures of merit: monthly energy consumption, in kWh, and energy use per page, in Wh. The results given by the procedures are intended to give accurate measurements under representative conditions that may not match actual usage of any given machine. Actual energy data depends primarily on the amount of time the machine is in use in each mode, and the nominal volume of imaging performed. Since this varies widely among users, certain assumptions were made. The four key assumptions in the final version of the copier, printer and fax procedures are:

1. Hours of use: 10.5 hours/per day, 22 days per month, for a total of 231 hours per month. Twenty hours of warm-up time is subtracted to leave 211 hours for idle usage, standby and an energy-saver mode.

2. Standby and energy saver time: These times are dependent on the nominal volume and use, taken from the job matrix included in the procedure (Table 1 of each procedure), and the imaging time, which is calculated according to machine speed and the amount of time the machine takes to go into or come out of an energy-saver mode (energy-saver

delay time). It is assumed that of the 211 hours, 176 hours are daily usage, and 35 hours are time the machine is left on overnight or on the weekend. If the machine has an auto shut-off mode, there are 3 hours for overnight/weekend usage.

3. Warm-up time: The machine is turned on once per day, 20 days per month, unless the machine has an auto shut-off mode. While there are often 21-22 working days in a 30 day month, the use of 20 days in the test procedure reflects the fact that some machines are not turned off at night. If the machine automatically shuts itself off after some period of time, or at a specified time, then the machine will have a warm-up period 22 days a month.

4. Distribution of copies: The test procedure requires that a monthly copying or printing volume be identified. From this selection comes the number of copies or printed pages to be made in an hour, which is then specified as the product of the number of jobs, the number of originals and the number of copies per original or the number of printed pages. Jobs are spaced evenly throughout an hour, which is not necessarily a reflection of how most copiers are used. In reality, it can be expected that most copiers will have some periods of non-use; for instance over the lunch hour, most copiers will sit idle. Lacking accurate usage patterns for copiers, this assumption will stand until a better method for calculating distribution of copies is assessed.

Each of these assumptions can be questioned. Each can be probed through a combination of measured usage patterns; sensitivity analyses in which the assumptions are changed and the results of the test procedures are recalculated; and comparisons of measured energy use over a period of a time (a week or longer) with energy consumption predicted by the test procedures. The test procedures also specify, as an alternative, that the testers can use actual usage data in the formulas. Chapter 5 is dedicated to exploring the use of these methods for measuring the energy consumption of particular machines. This chapter will explain why some of the assumptions were made, and the changes made to each draft of the procedure.

These test methods provide a procedure for measuring the energy consumption of the machine and associated accessories in various operating modes. They do not reflect the total energy required to produce a page. They do not, for example, include the energy required to manufacture the paper or the machine. They are intended to permit rating the energy requirements of products by a method that will permit accurate energy efficiency comparisons of each product with all other similar products.

II. Test Procedure for Measuring the Energy Consumption of Copiers.

There was an existing copier test procedure, written in 1982 by a member of the ASTM F05 committee (ASTM). This test procedure lacked many important inclusions for measuring the energy consumption of copiers, particularly the energy use in an energy saving mode. I have made a series of revisions and guided the revised procedure through the ASTM review process. Following is an account of the changes to each revision.

A. Revision to Original Draft

As mentioned, the original F757 test procedure for copiers did not include an energy-saver mode. Therefore, the procedure was revised to include the testing of energy consumption in an energy-saver mode for one hour. In the calculations for total energy use of the machine I assumed the machine would be in an energy saver mode for half the time it was idle, and in a standby mode the other half of the time. I also changed the hours of use; instead of assuming the machine would be on for 9 hours a day, 5 days a week, I assumed it would be on 24 hours per day for 2 days of each month in addition to the 9 hours per day. Therefore, the new average would be 10.5 hours per day, each month. I added to the original test procedure the necessity for users to test the machine twice, once for single-sided (simplex) copying, and once for double sided (duplex) copying.

B. Revisions to Draft 2.

A suggestion was made at this point to change the amount of time the machine would be in an energy-saver mode from a fixed amount of time to a variable that would depend on copy volume. This was not considered necessary, since these tests, as mentioned earlier, are to be used for comparative purposes only. Copiers with differing copy volumes are not likely to be compared, since low and high volume machines are not normally compared on a basis of energy use. However, the seventh draft of the procedure does include these changes, for reasons discussed in section II.G.

C. Revisions to Draft 3 and 4.

No significant changes were made to draft 3 or 4. I made some small editorial changes, and changes to wording of definitions.

D. Revisions to Draft 5.

It was pointed out that some copiers have an auto shut-off mode, by which the copier can be switched off automatically either at a specified time, or after a timed period of non-use. Therefore, I revised the procedure so it had two different cases, one with an auto shut-off mode, and one without. Hours of use and the method of calculation were changed to suit copiers that have an auto shut-off. Users can make calculations according to the method that suits the copier being tested.

The suggestion to change the amount of time the copier was in an energy-saver mode was made again. In response to this, I added a part to section 4 that suggests users can use actual usage data for their copier if they would like to know actual energy use of a particular copier. If the amount of time the copier spends in each of the five modes is known, those hours of use can be used to calculate the energy consumption of the machine.

E. Revisions to Draft 6: Draft 7.

In this draft, final changes were made to the amount of time the copier would spend in an energy-saver mode, since the time the copier takes to go into and come out of the energy-saver mode is often a variable for like machines. This could effect the amount of time each machine spends in an energy saver mode. Changes were made according to these factors, and to the copy volume of the machine. There was no necessity to make the changes with consideration to copy volume, as mentioned above. However, since the energy-saver mode would now become a variable, consideration for these factors were included.

The amount of time a copier would take to go into or come out of an energy-saver mode has a strong effect on the amount of time it spent in the energy-saver mode. These effects were discussed in detail in Chapter 3, section VI.A.2. Table 2, Calculations for Copying Time was added to the procedure. For this table, users choose the appropriate copier speeds taken from manufacturer's data, and puts them into the formula that relates to the volume at which the machine is being tested. An energy-saver delay time is included in the calculations in section 10. These values are measured separately by users.

The energy-saver time per month is found with an equation users can easily calculate. First, the copying time (obtained from Table 2) is subtracted from 60 minutes; this number is the amount of time the machine is idle. The energy-saver delay time, which is measured by users, is multiplied by the number of jobs performed (obtained from Table 1). This number is subtracted from the amount of time the machine is idle, then multiplied by 176 hours per month. 176 hours per month is obtained from the assumption that the machine will be in active use 8 hours per day. Since it is assumed the machine is on 211 hours per month (10.5 hours per day), there is 35 hours of use that the machine could potentially be in an energy-saver mode. These 35 hours are therefore added to the number above. Then, using 5 as an assumed number of times the copier will go into and come out of an energy saver mode, 5 times the energy-saver delay time is subtracted from the total. The equation therefore becomes:

$$\frac{[(60\text{ min.} - C_t) - (E_{sdt} * j)] * 176\text{ hr/month}}{60\text{min.}} + 35\text{ hr/month} - \frac{(5 * E_{sdt})}{60\text{ min.}}.$$

C_t = Copying time
E_{sdt} = Energy-Saver delay time
j = number of jobs

F. Seventh Draft of the ASTM Test Method for Copiers

Draft 7 is the version that is currently under review with the ASTM committee. The January, 1994 ASTM meeting will decide whether this procedure will be published in the 1994 ASTM book of standards.

Seventh Draft: October 18, 1993

Designation: F 757 - 82 (Re-approved 1987)$^{\varepsilon 1}$

Standard Test Method for Determining Energy Consumption of Copier and Copier-Duplicating Equipment[1]

This standard is issued under the fixed designation F 757; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last re-approval. A superscript epsilon (ε) indicates an editorial change since the last revision or re-approval..

$\varepsilon 1$ NOTE--Sections 3 through 5 were renumbered editorially in November 1986.

---

1. Scope

1.1 This procedure provides a test method by which copiers, copier-duplicators, accessories, and similar office imaging devices can be rated for energy consumption.

1.2 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitation prior to use.*

2. Referenced Document

2.1 *ASTM Standard:*

---

[1] This test method is under the jurisdiction of ASTM Committee F-5 on Business Copy Products and is the direct responsibility of Subcommittee F05.04 on Electrostatic Copy Products.

Current edition approved March 26, 1982. Published May 1982.

F 335 Standard Definitions of Terms Relating to Electrostatic Copying[2].

2.2 *ASTM Standard:*

F 995 Standard Test Method for Estimating Toner Usage in copiers Utilizing Dry Two-Component Developer[3]

3. Descriptions of Terms Specific to This Standard

3.1 For definitions of terms used in this method, see F 335 Standard Definitions of Terms Relating to Electrostatic Copying.

3.2 *standard copy*--a sheet imaged on one side that measures 81/2 by 11 in. (216 by 280 mm).

3.3 *copying*--the machine condition that exists from the beginning to the end of the cycle that produces a copy or copies.

3.4 *plug-in mode*--the condition that exists when the machine is connected to an appropriate electrical source and is not turned on.

3.5 *warm-up mode*--the condition that exists when the machine is turned on from a plug-in mode and prior to reaching the stand-by mode.

3.6 *stand-by mode*--the condition that exists when the machine is not making copies, has reached operating conditions, but has not yet entered into energy-saver mode.

3.7 *energy-saver mode*--the condition that exists when the machine is not making copies, has previously reached operating conditions but is consuming less power than when the machine is in stand-by mode. Some copy machine instruction manuals use the term stand-by mode for this condition.

3.8 *automatic shut-off mode*--variable energy state into which the copier can be programmed to place itself after a period of time of non-use or at a specified time.

3.9 *standard month*--thirty 24-h days.

3.10 *standard work day*--10.5 h[4].

3.11 *standard work month*--22 standard work days.

---

[2]*Annual Book of ASTM Standards*, Vol. 15.09

[3]*Annual Book of ASTM Standards*, Vol. 15.09

[4]Due to change in use practice, the standard work day was changed from 9 to 10.5h.

3.12 *accessories*-- any device that expands the capability of the equipment beyond its normal operating mode. An accessory for purposes of energy tests shall be defined as one that is under the control of the operator.

3.13 *copying energy*--the energy consumed during a designated copying mode exclusive of stand-by and plug-in energy.

3.14 *machine energy*--the energy consumed by a copier that is plugged-in 24 h per day and turned on 10.5 h[3] but that is not making copies.

3.15 *recovery energy*--the amount of energy needed in excess of energy-saver mode energy to pass from the energy-saver mode to the stand-by mode.

3.16 *copying time*--the amount of time that the nominal jobs are run when testing copying energy.

3.17 *idle time*--the amount of time that the machine is not copying when testing copying energy.

3.18 *energy-saver delay time*--the amount of time that the machine takes to go into and to come out of the energy saver mode.

3.19 *energy-saver time*--the amount of time that the machine is in an energy-saver mode.

3.20 *nominal volume*--one of the convenient levels into which the entire range of monthly volumes have been divided.

3.21 *copier speed, first copy*--one of the convenient levels for which the copier's speed is measured. This is the amount of time the copier takes to make the first copy of a job.

3.22 *copier speed, multi copy*--one of the convenient levels for which the copier's speed is measured. This is the amount of time the copier takes to make multiple copies after the first copy of a job.

3.23 *nominal copies per day*-- the number of nominal copies produced on a single machine during a nominal copying day.

3.24 *run mode*--a particular combination of originals per job and copies per original.

3.25 *job*--making copies from one or more originals without interruption or delay between originals.

3.26 *cycle out*--the condition which exists when the machine has finished copying, and has returned to a stand-by mode.

4. Summary of Test Method

4.1 The standard energy consumption rating is determined (using a watt-hour meter) for a copier while the machine is in a simulated customer installation performing one eighth of a typical day's copying jobs. The typical day's jobs are based (size, number of originals, and copies per original) on the nominal volume (see Table 1). The simulated customer installation can be calculated with actual usage data (see 4.3), or can be based on the following assumptions, that the copier will typically:

4.1.1 Be connected to a live power line for thirty 24 h days (720h) per month.

4.1.2 Be turned on or off or both each of 22 work days per month.

4.1.3 Go through a warm-up cycle (if required) once each of 20 work days each month, unless the copier has an automatic shut off. In the latter case, it will go through a warm-up cycle once each of 22 days each month.

4.1.4 Be left on 24 h per day for 2 days of each standard work month, unless the copier has an automatic shut-off.

4.1.5 As a result of items 4.1.2 and 4.1.3, be left on for an average of 10.5 h each of the 22 days, unless the copier has an automatic shut-off. In the latter case, it will be left on an average of 9 h each of the 22 days.

4.1.6 Be in an energy-saver mode some amount of time depending on the nominal volume and use from Table 1, the copying time from Table 2, and the energy-saver delay time.

4.1.7 Perform a typical day's copying jobs each of the 22 work days each month.

4.2 The energy consumption per copy or the typical month's energy consumption rating (kWh per month) are determined using calculations based on the test data.

4.3 As an alternative you can use actual usage data for estimated hours of use in these formulas, and in section 10. When making comparisons of like machines, it is recommended to use the same usage data.

5. Significance and Use

5.1 This test method provides a procedure for measuring the energy consumption of the product and associated accessories in various operating modes. It does not reflect the total energy required to produce a copy. It does not, for example, include the energy required to manufacture the paper or the machine. It is intended to permit rating the energy requirements of products by a method that will permit accurate energy efficiency comparisons of each product with all other similar products.

6. Apparatus and Supplies

6.1 *Watt-Hour Meter*, one per phase, accurate to three figures.[5]

6.2 *Timer*-- a timing device accurate to one second.

6.3 *Test Target*--A ten pitch, pica, 45 lines of lower case "k" character, 65 characters per line (2925 total characters), with a 1-in. (25-mm) clear border around the typed area, and on white paper. This target is prepared by the user. Alternately, the test target with 8 % coverage (PCN 12-609950-11) from ASTM F 995, Standard Test Method for Estimating Toner Usage in Copiers Utilizing Dry Two-Component Developer can be used.

6.4 *Paper*-- should be 81/2 by 11 in. (216 by 280 mm), 20-lb bond or where not applicable, use machine manufacturer's recommended mid-point range of paper weight.

7. Sampling

7.1 The energy rating should be that for a device representative of the commercially available equipment. Any modification of the product or additional configurations that significantly alter energy consumption will require re-ratings or additional ratings.

7.2 Those copiers configured with automatic duplex option should be rated twice, once at 100 % single-sided copy and once at 100 % of two-sided copies (each side counted as one copy).

7.3 The copier(s) to be evaluated should be set to within the manufacturers operating specifications.

---

[5]For certain low-volume copiers that consume little energy, the Duncan model EM-10 which reads to 0.1 Wh per count, or equivalent, has been found suitable for use (Section 12.2). Duncan models are available from Duncan Electric Co., Lafayette, IN, and the General Electric model is available from General Electric, Schenectady, NY.

8. Preparation of Apparatus

8.1 *Test Conditions:*

8.1.1 The room ambient shall be within a range of 21 ±3° C; 40 to 60 % relative humidity.

8.1.2 The working voltage shall be machine-rated voltage ±2 %.

8.1.3 The machine shall be at least 2 ft (610 mm) from any wall or air obstacle.

8.1.4 All supplies used shall be those specified by the copier manufacturer and preconditioned for a minimum of 24 h at the room ambient temperature prior to evaluating the copier energy rating.

8.1.5 AC power shall be supplied as a true sine wave with no more than 3 % harmonic distortion.

8.1.6 The power frequency must be rated frequency ±0.1 Hz.

TABLE II.1 Nominal Parameters for Each Nominal Volume

		Nominal Jobs (1/8 day)n[A]			
Nominal Monthly Volume, Copies per Month	Nominal Day's Copies	Number of Jobs	Number of Originals	Number of Copies/ Original	Job Interval, min.
200	8	1	1	1	60.0
500	24	3	1	1	20.0
1 000	48	3	1	2	20.0
2 500	112	7	1	2	8.6
5 000	224	7	2	2	8.6
10 000	432	9	2	3	6.6
25 000	1 152	16	3	3	3.7
40 000	1 824	19	3	4	3.1
80 000	3 600	18	5	5	3.3
100 000	4 800	3	10	20	20.0
280 000	13 200	2	15	55	30.0
500 000	22 800	2	15	95	30.0
1 000 000	45 600	2	15	190	30.0

[A] n = number of jobs * number of originals * number of copies per original

8.1.7 The manufacturer will define the configuration (including accessories) of the machine to be tested, the volume at which it will be rated (Table 1), and both the first copy for the nominal volumes and copier speeds for which the manufacturer intends to market the product.

8.1.8 When operator speed is a variable affecting energy use the manufacturer should use and specify a normal operating time.

NOTE--During the test cycle, the machine should be allowed to cycle out after the required number of copies per original have been completed. This aspect does not apply to those machines having automatic document feeders or other features that allow for continuous operation without cycling out.

Example: Document change time used--3.0 s

TABLE II.2 Calculation for Copying Time

Nominal Monthly Volume, Copies per Month	Number of Jobs (*j*)	Number of Originals	Number of Copies/ Original	Copying Time Minutes per Hour (C_t)
200	1	1	1	1/X[B]
500	3	1	1	3/X
1 000	3	1	2	3/X+3/Y[C]
2 500	7	1	2	7/X+7/Y
5 000	7	2	2	7/X+21/Y
10 000	9	2	3	9/X+45/Y
25 000	16	3	3	16/X+128/Y
40 000	19	3	4	19/X+209/Y
80 000	18	5	5	18/X+432/Y
100 000	3	10	20	3/X+897/Y
280 000	2	15	55	2/X+1648/Y
500 000	2	15	95	2/X+2848/Y
1 000 000	2	15	190	2/X+5698/Y

[B] X = copier speed, first copy

[C] Y = copier speed, multi copy

8.1.9 The test should be discontinued if an unusually high number of machine problems occur. Excess machine stoppages may distort the overall energy rating. A reasonable number of paper jams that can be readily cleared by the operator should not be considered reason to discontinue the test.

9. Procedure

9.1 Steps 9.1.1, 9.1.2, 9.1.3, 9.1.4, 9.1.5 and 9.1.7 of this procedure should be completed once for each test machine. The data from 9.1.1, 9.1.2, 9.1.3, 9.1.4 and 9.1.6 will apply to all nominal volumes for which the machine is being rated. The data from 9.1.5 will only apply to one configuration and must be repeated for all other configurations for which the machine is being rated. Prior to the start of this test, the machine should be plugged in to a live power line but turned off and stabilized at room ambient conditions for at least 12 h. An appropriate watt-hour meter should be in line with the machine, ready to give an accurate indication of machine energy consumption without disruption of the energy source. This test should be run at the copier setting that, in the opinion of the evaluator, is the one yielding the best appearing copy.

9.1.1 *Copying Time*--Choose the appropriate formula in Table 2 that matches the monthly volume for which the machine is being rated. Using the manufacturer's values for copier speeds, where X is the number of copies per minute for the first copy, and Y is the number of copies per minute for multiple copies, follow the appropriate formulas. Record the copying time in Figure 1.

9.1.2 *Plug-In Mode Energy*--Read and record the watt-hour meter indication and the time (or start the stop watch or timer). After 1 h, read and record the watt-hour indication again. The difference between the two readings of the watt-hour meter is the observed data for plug-in mode energy use. Record the result in Fig. 1, Test Results Part A. If it is known that the test machine consumes no energy during the plug-in mode, enter a zero for the observed data for plug-in energy use and omit this step.

9.1.3 *Warm-Up Mode Plus Stand-By Mode Energy*--For copiers having an energy-saver mode feature, disable the energy-saver mode. With the machine in a stabilized plug-in mode, read and record the watt-hour meter indication and the time (or start the stopwatch or timer). Turn the machine on and allow the machine to warm up and stabilize in the ready mode. After 1 hr, read and record the watt-hour indication again. The difference between the two readings of the watt-hour meter is the observed data for warm-up mode plus stand-by mode energy use. Record the result in Fig. 1, Test Results Part B. If it is known that the machine uses no energy in the warm-up mode (as defined by this procedure) omit this step and proceed to 9.1.3.

9.1.4 *Stand-by Mode Energy*--For copiers having an energy-saver mode feature, disable the energy-saver mode. At the conclusion of the previous 1 h measurement (9.1.2) leave the machine turned on. After 1 h, record the watt-hour reading. The difference between the watt-hour reading at the start and finish of the hour is the observed data for stand-by mode energy. Record the result in Fig. 1, Test Results Part C.

9.1.5 *Energy-Saver Mode Energy*--For copiers having an energy-saver mode feature, enable the energy-saver mode. If the energy-saver mode is automatic, let machine enter energy-saver mode. When it has entered energy-saver mode, read and record the watt-hour meter and the time. After 1 h, record the watt-hour reading again. The difference between the watt-hour reading at the start and finish of the hour is the observed data for energy-saver mode energy. Record the result in Fig. 1, Test Results Part D. If it is known that the machine does not have an energy-saver mode (as defined by this procedure) record the stand-by energy (results from Part C) in Fig. 1, Test Results Part D.

9.1.6 *Copying Energy Plus Stand-by Energy*--With the machine in a stand-by mode, read and record the watt-hour indication and the time (or start the stopwatch or timer). Using a nominal original or originals (6.2) perform the nominal jobs (Table 1) for the nominal volume and configuration for which the machine is being rated. Equally space the jobs throughout the 1 h allocated for this part of the test (Table 1 for job time interval). The operator should change the original or originals in such a manner as to have a minimal impact on job time and energy use (see 8.1.8 for exceptions). After the jobs have been performed and 1 h has elapsed, read and record the watt-hour meter indication again. The difference between the two readings of the watt-hour meter is the observed data for copying energy use. Record the result in Fig. 1, Test Results Part E.

9.1.7 *Energy-Saver Delay Time*--For copiers having an energy-saver mode feature, if the time to enter the energy-saver mode is adjustable, set it to one minute. Make a copy. Using the timer, record the amount of time it takes the machine to enter an energy-saver mode. Record the time in minutes and seconds. If the machine is one which is manually placed in the energy-saver mode, activate the energy saver switch when the machine has cycled out, and then record the time it takes to reach the energy saver mode. The copier should stay in the energy-saver mode for 1 hour. Using the timer, record the amount of time it takes the machine to come out of the energy-saver mode, in minutes and seconds. Add this time to the amount of time it took the copier to go into an energy-saver mode and record the result in Fig. 1, Test Results Part F.

9.1.8 *Recovery Energy plus Energy-Saver Energy*--Repeat the steps in 9.1.5, when the machine enters the energy-saver mode, read and record the watt-hour indication and the time (or start the stopwatch or timer). At one hour minus the time needed for the machine to come out of the energy-saver mode, bring the machine out of the energy-saver mode. When the machine reaches the stand-by mode, the time should show one hour. Record the watt-hour meter reading. The difference between these two readings is the Recovery Energy plus Energy-Saver Energy. Record this in Figure 1, Part G.

9.1.8 Repeat the procedure in 9.1.6 with the machine set to duplex and enter in the appropriate sections in Figure 1.

10. Calculation

10.1 Enter the number of copies *n* (Table 1, Footnote A), the monthly volume *N* (*n* * 176), copying and idle time C_t and I_t (Table 2), and the number of jobs *j* into Fig. 1.

10.2 Calculate the data from the following sections for 100 % single sided copies and list in the appropriately designated section in Fig. 1. Also see 4.3.

10.2.1 Enter the data obtained from step 9.2.1 under Copying Time, C_t in Figure 1.

10.2.2 Enter the data obtained from steps 9.1.2, 9.1.3, 9.1.4, 9.1.5, 9.1.6, 9.1.7 and 9.1.8 under Test Results, Parts A, B, C, D, E, F and G.

10.2.3 Calculate warm-up energy (B - C) and record under Part H.

10.2.4 Calculate copying energy E_c using (E - C) and record under Part I.

10.2.5 Calculate the recovery energy per month. Subtract the energy-saver energy from the recovery energy plus energy-saver energy and multiply this difference by the number of jobs in the test, and by 176. $E_{rc} = (G - D) * j * 176$. Record this result in Fig. 1, Part J.

10.2.6 Calculate energy per copy (E_c/n). Multiply E_c/n by 0.001 to determine kilowatt hours. Record both results under Part K.

10.2.7 Calculate the energy-saver time per hour. Multiply the number of jobs *j* by the energy saver delay time, and subtract the total from the idle time I_t. ($I_t - j * F$). If this value is less than zero, enter zero. Record under Part L.

10.2.8 Calculate the fraction of energy-saver time. Divide the energy-saver time per hour by 60 minutes per hour (L/60). Record under Part M.

10.2.9 Calculate plug-in energy per standard month for copiers without an auto shut-off (A * 489 h/month). Record under Part N.

10.2.10 Calculate warm-up plus stand-by energy per standard month for copiers without an auto shut-off (B * 20 h/month). Record this result under Part O.

10.2.11 For copiers with an energy-saver mode feature, calculate the amount of time a copier without an auto shut-off is in an energy-saver mode per month ((M * 176)+35-(5 * F/60)). Record this result under Part P.

10.2.12 Calculate stand-by energy per standard month for copiers without an auto shut-off key (C * (211-P) h/month). Record under Part Q.

10.2.13 For copiers without an auto shut-off and having an energy-saver mode feature, calculate energy-saver energy per standard month (D * P h/month) and record under Part R.

10.2.14 For auto shut-down copiers calculate plug-in energy per standard month (A * 519 h/month). Record under Part S.

10.2.15 For auto shut-down copiers calculate warm-up plus stand-by energy per standard month (B * 22 h/month). Record this result under Part T.

10.2.16 For auto shut-down copiers with an energy-saver mode feature, calculate the amount of time the copier is in an energy-saver mode per month ((M * 176)+3-(3 * F/60)). Record this result under Part U.

10.2.17 For auto shut-down copiers calculate stand-by energy per standard month (C * (179-U)h/month) and record under Part V.

10.2.18 For auto shut-down copiers having an energy-saver mode feature, calculate energy-saver mode energy per standard month (D * U h/month) and record under Part W.

10.2.19 Calculate machine energy per standard month E_m = [N+O+Q+R] or [S+T+V+W] for copiers with an auto shut-off option. This is the energy consumed by the machine independent of copy volume. Record this result under Part X.

10.2.20 Calculate the total energy per month E_t. Total energy equals machine energy plus copying energy.

$$E_t = (E_m) + (E_c/n + E_{rc})N$$

Record the result under Y.

10.2.21 Calculate the average total energy per copy as follows:

$$E_{tave} = \frac{E_m + (E_c/n + E_{rc})N}{N}$$

Record under Z.

10.3 Calculate the data from 10.2.1 to 10.2.20 for 100 % duplexed copies and list in the appropriately designated section in Fig. 1.

FIG. II.1 Sample Data Sheet

Machine Tested ____

		Single-sided Copies	Duplexed Copies
Monthly volume N (n * 176)		_____	
Number of copies n in test (from Table 1)		_____	
Copying Time C_t (from Table 2)		_____ min.	
Idle Time, I_t [60 minutes - C_t]		_____ min.	
Number of Jobs j in test (from Table 1)		_____	
Test Results (1-h Test)			
A.	Plug-in energy	_____ Wh	
B.	Warm-up plus Stand-by energy	_____ Wh	
C.	Stand-by energy	_____ Wh	
D.	Energy-saver energy	_____ Wh	
E.	Copying energy plus Stand-by	_____ Wh	_____ Wh
F.	Energy-saver delay time	_____ min.	
G.	Recovery Energy plus Energy-Saver Energy	_____ Wh	
Calculations, All Copiers			
H.	Warm-up energy, E_r [B-C]	_____ Wh	
I.	Copying energy, E_c [E-C]	_____ Wh	_____ Wh
J.	Recovery Energy E_{rc} [G-D]	_____ Wh	
K.	Copying energy per copy, E_c/n	_____ Wh	_____ Wh
	E_c/n * 0.001 =	_____ kWh	_____ kWh
L.	Energy saver time per hour [I_t - j * F]	_____ min./hr	
M.	Fraction energy-saver time [L/60]	_____	
Calculations, Copiers Without Auto Shut-off			
N	Plug-in energy per standard month [A * 489]	_____ Wh	
O.	Warm-up plus Stand-by energy per standard month [B * 20]	_____ Wh	
P.	Energy-saver time per month [(M * 176)+35-(5 * F/60)]	_____ min.	
Q.	Stand-by energy per standard month [C * (211-P)]	_____ Wh	
R.	Energy-saver energy per standard month [D * P]	_____ Wh	
Calculations, Copiers With Auto Shut-off			
S.	Plug-in energy per standard month [A * 519]	_____ Wh	
T.	Warm-up plus Stand-by energy per standard month [B * 22]	_____ Wh	
U.	Energy-saver time per month [(M * 176)+3-(3 * F/60)]	_____ min.	
V.	Stand-by energy per standard month [C * (179-U)]	_____ Wh	
W.	Energy-saver energy per standard month [D * U]	_____ Wh	
Calculations, All Copiers			
X.	Machine energy per standard month--Independent at Volume E_m = [N+O+Q+R] or [S+T+V+W]	_____ Wh	
Y.	Total energy per month $E_t = E_m + (E_c/n + E_{rc})N$	_____ Wh	_____ Wh
Z.	Average total energy per copy $E_{tave} = \dfrac{E_m + (E_c/n + E_{rc})N}{N}$	_____ Wh	_____ Wh

11. Report

11.1 If several identical machines are rated, the average energy rating should be reported. If the results for each machine differ by more than 10 %, the test should be repeated.

11.2 All data recorded should be reported to a minimum of three significant figures.

12. Precision and Bias

12.1 Precision and bias of the energy rating may be determined with calculations, projections, extrapolations or all three, as long as the overall accuracy is not significantly affected. However, the resulting energy rating must be based upon the conditions specified in this procedure.

12.2 All time-measuring devices shall have an accuracy of ±0.5 %. All other measuring devices should provide a ±2 % accuracy.

12.3 It is not practicable to specify the precision and bias of the procedure in Test Method F 757 for measuring the energy consumption of copier and copier duplicating equipment, because there is no standard report.

III. Test Procedure for Measuring Energy Consumption of Printers.

When writing the printer test procedure, a number of considerations had to be addressed. I tried to base the printer test procedure as much as possible on the copier test procedure for ease of use, but in some respects different inclusions had to be made, since copying and printing technologies and use differ.

Each of the five modes are tested, as with the copier test procedure. The hours of use mirror those of the copier test procedure drafts. As with the copier test procedure, if the printer is capable of duplexing, the energy consumption in the print mode must be measured twice, once for simplex printing and once for duplex printing.

Copiers do not need a digital interface that sends information needed to be imaged. With a printer, use of a computer to send information to a printer might slow or speed up the machine. When speed is a variable, energy consumption could also vary since energy is dependent on time. The same argument is true with different page description languages. Configuration, resolution and contrast could also effect the energy consumption of the machine.

The ASTM committee can not recommend the use of one particular page description language, or a brand or type of computer to send the information, since it is a non-biased organization. Configuration, resolution setting, and contrast could also effect the energy consumption. Besides the type or brand of computer, the manufacturer shall describe each setting at which the machine is to be tested.

I decided that a device other than a computer is needed to send information to the printer being tested. The Anacom Smartbox, which is referenced in the ASTM printer procedure below, or another similar device was recommended. This type of device takes the place of a computer and downloads text and/or graphic images to a printer with the use of EPROMs and either serial or parallel ports.

Based on these factors, a first draft of a printer test procedure was written. Subsequent changes to the procedure follow.

A. Revisions to Draft 1.

No significant changes were made.

B. Revisions to Draft 2.

Most of the changes to this version echoed the changes made to the copier draft 6 (see section II.D). Also, in previous versions, the user tested for a variety of configurations and resolution settings. This was changed to suggest the user could test for each configuration and resolution setting, but that the manufacturer should specify at which settings the machine would be rated.

C. Revisions to Draft 3.

Because the time the printer would spent in the energy-saver mode was originally the same as that for copiers, the times were changed to echo the copier procedure (see section II.E). The nominal page volume for the printer was also thought to be too high, so was changed accordingly.

D. Fourth Draft of the ASTM Test Procedure for Printers

Draft 4 is the version that is currently under review with the ASTM committee. It is a test method for black-and-white non-impact personal computer printers, accessories, and similar office imaging devices can be rated for energy consumption. The procedure could also be used for impact and color printers, but since these two types of printers vary in technology and definition, I felt it was better to concentrate on the more widely used black and white, non-impact printers.

The January, 1994 ASTM meeting will decide whether this procedure will be published in the 1994 ASTM book of standards.

Fourth Draft: October 18, 1993

New Standard Test Method for Determining Energy Consumption of Personal Computer Printers

Draft Version, do not quote

1. Scope

1.1 This procedure provides a test method by which black-and-white non-impact personal computer printers, accessories, and similar office imaging devices can be rated for energy consumption.

1.2 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitation prior to use.*

2. Referenced Document

2.1 *ASTM Standard:*

F 335 Standard Definitions of Terms Relating to Electrostatic Copying[6].

2.2 *ASTM Standard:*

F 757 Standard Test Method for Determining Energy Consumption of Copier and Copier-Duplicating Equipment[7].

2.3 *ASTM Standard:*

F 909 Standard Terminology Relating to Printers

---

[6] *Annual Book of ASTM Standards*, Vol. 15.09

[7] *Annual Book of ASTM Standards*, Vol. 15.09

3. Descriptions of Terms Specific to This Standard

3.1 For definitions of terms used in this method, see F 335 Standard Definitions of Terms Relating to Electrostatic Copying.

3.2 For definitions of terms used in this method, see F 757 Standard Test Method for Determining Energy Consumption of Copier and Copier-Duplicating Equipment.

3.3 For definitions of terms used in this method, see F 909 Standard Terminology Relating to Printers

3.3 *printing*--the machine condition that exists from the beginning to the end of the cycle that produces a page or pages.

3.4 *warm-up mode*--the condition that exists when the machine is turned on from a plug-in mode and prior to printing pages.

3.5 *stand-by mode*--the condition that exists when the machine is not printing, has reached operating conditions, but has not yet entered into an energy-saver mode.

3.6. *energy-saver mode*--the condition that exists when the machine is not printing, has previously reached operating conditions but is consuming less power than when the machine is in stand-by mode.

3.7. *printing energy*--the energy consumed during a designated printing mode exclusive of stand-by and plug-in energy.

3.8 *machine energy*--the energy consumed by a printer that is plugged-in 24 h per day and turned on 10.5 h[3] but that is not printing pages.

3.9 *printing time*--the amount of time that the nominal jobs are run when testing printing energy.

3.10 *idle time*--the amount of time that the machine is not printing when testing printing energy.

3.11 *machine speed, first copy*--one of the convenient levels for which the machine's speed is measured. This is the amount of time the machine takes to produce the first page of a job.

3.12 *machine speed, multi copy*--one of the convenient levels for which the machine's speed is measured. This is the amount of time the machine takes to produce multiple pages after the first page of a job.

3.12 *standard pages per day*-- the number of standard pages produced on a single machine during a standard printing day.

3.13 *job*--printing pages without interruption or delay between pages.

3.14 *cycle out*--the condition which exists when the machine has finished printing a page, and has returned to a stand-by mode.

4. Summary of Test Method

4.1 The standard energy consumption rating is determined for a printer while the machine is in a simulated customer installation performing one eighth of a typical day's printing jobs (using a watt-hour meter). The typical day's jobs (size and number of pages) are based on the standard volume (see Table 1). The simulated customer installation can be calculated with actual usage data (see 4.3), or can be based on the following assumptions, that the printer will typically:

4.1.1 Be plugged in to a live power line for thirty 24 h days (720h) per month.

4.1.2 Be turned on or off or both, each of 22 work days per month.

4.1.3 Go through a warm-up cycle (if required) once each of 20 work days each month.

4.1.4 Be left on 24 h per day for 2 days of each standard work month.

4.1.5 As a result of items 4.1.2 and 4.1.3, be left on for an average of 10.5 h each of the 22 days.

4.1.6 Be in an energy-saver mode some amount of time depending on the nominal volume and use from Table 1, the printing time from Table 2, and the energy-saver delay time.

4.1.7 Perform a typical day's printing jobs each of the 22 work days each month.

4.2 The energy consumption per printed page or the typical month's energy consumption rating (kWh per month) are determined using calculations based on the test data.

4.3 As an alternative you can use actual usage data in these formulas. When making comparisons of like machines, it is recommended to use the same usage data.

5. Significance and Use

5.1 This test method provides a procedure for measuring the energy consumption of the product and associated accessories in various operating modes. It does not reflect the total energy required to produce a page. It does not, for example, include the energy required to manufacture the paper or the machine. It is intended to permit rating the energy requirements of products by a method that will permit accurate energy efficiency comparisons of each product with all other similar products.

6. Apparatus and Supplies

6.1 *Watt-Hour Meter*, one per phase, accurate to three figures.[8]

6.2 *Timer*-- a timing device accurate to one second.

6.3 *Anacom Smartbox Device*-- A device that takes the place of a computer and downloads text and/or graphic images to a printer with the use of EPROMs and either serial or parallel ports.[9]

6.4 *Test Target*--The test target with 8 % coverage, option XX in the Anacom Smartbox device should be used.

6.5 *Graphic Test Target*-- The test target with 8 % coverage, option XXX in the Anacom Smartbox device should be used.

6.4 *Paper*-- Should be 81/2 by 11 in. (216 by 280 mm), 20-lb bond or where not applicable, use machine manufacturer's recommended mid-point range of paper weight.

7. Sampling

7.1 The energy rating should be that for a device representative of the commercially available equipment. Any modification of the product or additional configurations that significantly alter energy consumption will require re-ratings or additional ratings.

7.2 Those printers configured with automatic duplex option should be rated twice, once at 100 % single-sided page and once at 100 % of two-sided pages (each side counted as one page).

7.3 The printer(s) to be evaluated should be set to within the manufacturers operating specifications.

---

[8]For certain low-volume copiers that consume little energy, the Duncan model EM-10 which reads to 0.1 Wh per count, or equivalent, has been found suitable for use (Section 12.2). Duncan models are available from Duncan Electric Co., Lafayette, IN, and the General Electric model is available from General Electric, Schenectady, NY.

[9]The Anacom Device can be ordered through Laser Supply, Inc. of Edgemont, PA. (800)422-0080.

7.4 Those printers equipped with more than one resolution setting should be rated at the highest resolution settings, using the manufacturer's recommended contrast settings. Resolution enhancement should be enabled.

8. Preparation of Apparatus

8.1 *Test Conditions:*

8.1.1 The room ambient shall be within a range of 21 ±3° C; 40 to 60 % relative humidity.

8.1.2 The working voltage shall be machine-rated voltage ±2 %.

8.1.3 The machine shall be at least 2 ft (610 mm) from any wall or air obstacle.

8.1.4 All supplies used shall be those specified by the printer manufacturer and preconditioned for a minimum of 24 h at the room ambient temperature and humidity prior to evaluating the printer energy rating.

8.1.5 AC power shall be supplied as a true sine wave with no more than 3 % harmonic distortion.

TABLE III.1 Nominal Parameters for Each Standard Volume

Nominal Monthly Volume, Pages per Month	Nominal Day's Pages	Nominal Jobs (1/8 day)n[A]		
		Number of Jobs	Number of Pages per Job	Job Interval
200	8	1	1	60 min.
500	24	3	1	20 min.
1 000	48	3	2	20 min.
2 500	112	7	2	8.6 min.
5 000	224	14	2	8.6 min.
10 000	432	18	3	3.3 min.
25 000	1 152	36	4	1.6 min.
40 000	1 824	57	4	62 sec
80 000	3 600	90	5	40 sec
100 000	4 800	100	6	36 sec
280 000	13 200	165	10	22 sec

[A] n = number of jobs * number of originals * number of pages per original

8.1.6 The power frequency must be rated frequency ±0.1 Hz.

8.1.7 The manufacturer will define the configuration (including accessories) of the machine to be tested and the volume at which it will be rated (Table 1). Normally, each printer will be rated for the standard volumes for which the manufacturer intends to market the product.

8.1.8 When operator speed is a variable affecting energy use the manufacturer should use and specify a normal operating time.

NOTE--During the test cycle, the machine should be allowed to cycle out after the required number of pages have been completed. This aspect does not apply to those machines having features that allow for continuous operation without cycling out.

Example: Document change time used--3.0 s

TABLE III.2 Calculation for Printing Time

Nominal Monthly Volume, Pages per Month	Number of Jobs (*j*)	Number of Pages per Job	Printing Time Minutes per Hour (S/R_t)
200	1	1	$1/X^B$
500	3	1	3/X
1 000	3	2	$3/X+3/Y^C$
2 500	7	2	7/X+14/Y
5 000	14	2	14/X+14/Y
10 000	18	3	18/X+36/Y
25 000	36	4	36/X+108/Y
40 000	57	4	57/X+171/Y
80 000	90	5	90/X+360/Y
100 000	100	6	100/X+500/Y
280 000	165	10	165/X+1485/Y

[B] X = machine speed, first page
[C] Y = machine speed, multi page

8.1.9 The test should be discontinued if an unusually high number of machine problems occur. Excess machine stoppages may distort the overall energy rating. A reasonable number of paper jams that can be readily cleared by the operator should not be considered reason to discontinue the test.

9. Procedure

9.1 Steps 9.1.1, 9.1.2, 9.1.3 and 9.1.4 of this procedure should be completed once for each test machine. The data from 9.1.1, 9.1.2, 9.1.3 and 9.1.4 will apply to all standard volumes for which the machine is being rated. The data from 9.1.5 will only apply to one configuration, one emulation, and one resolution setting and must be repeated for all other configurations, emulations and resolution settings for which the machine is being rated. Prior to the start of this test, the machine should be plugged in to a live power line but turned off and stabilized at room ambient conditions for at least 12 h. The Anacom device should be connected to the printer at least 12 hours prior to the test. An appropriate watt-hour meter should be in line with the machine, ready to give an accurate indication of machine energy consumption without disruption of the energy source. This test should be run at the printer setting that, in the opinion of the evaluator, is the one yielding the best appearing copy.

9.1.1 *Printing Time*--Choose the appropriate formula in Table 2 that matches the monthly volume for which the machine is being rated. Using the manufacturer's values for printer speeds, where X is the number of pages per minute for the first copy, and Y is the number of pages per minute for multiple copies, follow the appropriate formulas. Record the printing time in Figure 1.

9.1.2 *Plug-In Mode Energy*--Read and record the watt-hour meter indication and the time (or start the stop watch or timer). After 1 h, read and record the watt-hour indication again. The difference between the two readings of the watt-hour meter is the observed data for plug-in mode energy use. Record the result in Fig. 1, Test Results Part A. If it is known that the test machine consumes no energy during the plug-in mode, enter a zero for the observed data for plug-in energy use and omit this step.

9.1.3 *Warm-Up Mode Plus Stand-By Mode Energy*--With the machine in a stabilized plug-in mode, read and record the watt-hour meter indication and the time (or start the stopwatch or timer). Turn the machine on and allow the machine to warm up and stabilize in the ready mode. After 1 hr, read and record the watt-hour indication again. The difference between the two readings of the watt-hour meter is the observed data for warm-up mode plus stand-by mode energy use. Record the result in Fig. 1, Test Results Part B. If it is known that the machine uses no energy in the warm-up mode (as defined by this procedure) omit this step and proceed to 9.1.3.

9.1.4 *Stand-by Mode Energy*--For printers having an energy-saver mode feature, disable the energy-saver mode. At the conclusion of the previous 1 h measurement (9.1.2) leave the machine turned on. After 1 h, record the watt-hour reading. The difference between the watt-hour reading at the start and finish of the hour is the observed data for stand-by mode energy. Record the result in Fig. 1, Test Results Part C.

9.1.5 *Energy-Saver Mode Energy*--For printers having an energy-saver mode feature, enable the energy-saver mode. If the energy-saver mode is automatic, let machine enter energy-saver mode. When it has entered energy-saver mode, read and record the watt-hour meter and the time. After 1 h, record the watt-hour reading again. The difference between the watt-hour reading at the start and finish of the hour is the observed data for energy-saver mode energy. Record the result in Fig. 1, Test Results Part D. If it is known that the machine does not have an energy-saver mode (as defined by this procedure) record the stand-by energy (results from Part C) in Fig. 1, Test Results Part D.

9.1.6 *Printing Energy Plus Stand-by Energy*--With the machine in a stand-by mode, read and record the watt-hour indication and the time (or start the stopwatch or timer). Using a standard original (6.2) have the Anacom device perform the standard jobs (Table 1) for the standard volume and mode for which the machine is being rated. Equally space the jobs throughout the 1 h allocated for this part of the test (Table 1 for job time interval). The operator should send the original image in such a manner as to have a minimal impact on job time and energy use (see 8.1.8 for exceptions). After the jobs have been performed and 1 h has elapsed, read and record the watt-hour meter indication again. The difference between the two readings of the watt-hour meter is the observed data for printing energy use. Record the result in Fig. 1, Test Results Part E.

9.1.7 *Energy-Saver Delay Time*--For printers having an energy-saver mode feature, if the time to enter the energy-saver mode is adjustable, set it to one minute. Print a page. Using the timer, record the amount of time it takes the machine to enter an energy-saver mode. Record the time in minutes and seconds. If the machine is one which is manually placed in the energy-saver mode, activate the energy saver switch when the machine has cycled out, and then record the time it takes to reach the energy saver mode. The printer should stay in the energy-saver mode for 1 hour. Using the timer, record the amount of time it takes the machine to come out of the energy-saver mode, in minutes and seconds. Add this time to the amount of time it took the printer to go into an energy-saver mode and record the result in Fig. 1, Test Results Part F.

9.1.8 *Recovery Energy plus Energy-Saver Energy*--Repeat the steps in 9.1.4, when the machine enters the energy-saver mode, read and record the watt-hour indication and the time (or start the stopwatch or timer). At one hour minus the time needed for the machine to come out of the energy-saver mode, bring the machine out of the energy-saver mode. When the machine reaches the stand-by mode, the time should show one hour. Record the watt-hour meter reading. The difference between these two readings is the Recovery Energy plus Energy-Saver Energy. Record this in Figure 1, Part G.

9.1.9 Repeat the procedure in 9.1.5 with the machine set to duplex.

10. Calculation

10.1 Enter the number of pages n (Table 1, Footnote A) and the monthly volume N [n * 176] into Fig. 1.

10.2 Calculate the data from the following sections for 100 % single-sided copies and list in the appropriately designated section in Fig. 1.

10.2.1 Enter the data obtained from step 9.2.1 under Copying Time, C_t in Figure 1.

10.2.2 Enter the data obtained from steps 9.1.2, 9.1.3, 9.1.4, 9.1.5, 9.1.6, 9.1.7 and 9.1.8 under Test Results, Parts A, B, C, D, E, F and G.

10.2.3 Calculate warm-up energy [B - C] and record under Part H.

10.2.4 Calculate printing energy E_c using [E - C] and record under Part I.

10.2.5 Calculate the recovery energy per month. Subtract the energy-saver energy from the recovery energy plus energy-saver energy and multiply this difference by the number of jobs in the test, and by 176. $E_{rc} = (G - D) * j * 176$. Record this result in Fig. 1, Part J.

10.2.6 Calculate energy per page [E_p/n]. Multiply E_p/n by 0.001 to determine kilowatt hours. Record both results under Part K.

10.2.7 Calculate the energy-saver time per hour. Multiply the number of jobs j by the energy saver delay time, and subtract the total from the idle time I_t. ($I_t - j * F$). If this value is less than zero, enter zero. Record under Part L.

10.2.8 Calculate the fraction of energy-saver time. Divide the energy-saver time per hour by 60 minutes per hour (L/60). Record under Part M.

10.2.9 Calculate plug-in energy for copiers without an auto shut-off mode per standard month [A * 489 h/month]. Record under Part N.

10.2.10 Calculate warm-up plus stand-by energy for copiers without an auto shut-off mode per standard month [B * 20 h/month]. Record this result under Part O.

10.2.11 For printers with an energy-saver mode feature, calculate the amount of time a copier without an auto shut-off is in an energy-saver mode per month ((M * 176)+35-(5 * F/60)). Record this result under Part P.

10.2.12 Calculate stand-by energy per standard month for printers without an auto shut-off mode (C * (211-P) h/month). Record under Part Q.

10.2.13 For printers without an auto shut-off and having an energy-saver mode feature, calculate energy-saver energy per standard month (D * P h/month) and record under Part R.

10.2.14 For auto shut-down printers calculate plug-in energy per standard month (A * 519 h/month). Record under Part S.

10.2.15 For auto shut-down printers calculate warm-up plus stand-by energy per standard month (B * 22 h/month). Record this result under Part T.

10.2.16 For auto shut-down printers with an energy-saver mode feature, calculate the amount of time the copier is in an energy-saver mode per month ((M * 176)+3-(3 * F/60)). Record this result under Part U.

10.2.17 For auto shut-down printers calculate stand-by energy per standard month (C * (179-U)h/month) and record under Part V.

10.2.18 For auto shut-down printers having an energy-saver mode feature, calculate energy-saver mode energy per standard month (D * U h/month) and record under Part W.

10.2.19 Calculate machine energy per standard month E_m = [N+O+Q+R] or [S+T+V+W]. This is the energy consumed by the machine independent of volume. Record this result under Part X.

10.2.20 Calculate the total energy per month E_t. Total energy equals machine energy plus printing energy.

$$E_t = E_m + (E_p/n + E_{rp})N$$

Record the result under Y.

10.2.21 Calculate the average total energy per page as follows:

$$E_t = \frac{E_m + (E_p/n + E_{rp})N}{N}$$

Record under Z.

FIG. 1 Sample Data Sheet

Machine Tested ____

	Simplexed Copies	Duplexed Copies
Monthly volume N [n * 176]	_____	
Number of pages n in test (from Table 1)	_____	
Printing Time P_t (from Table 2)		
Idle Time, I_t [60 minutes - P_t]		
Number of Jobs j in test (from Table 1)		
Test Results (1-h Test)		
A. Plug-in energy	_____ Wh	
B. Warm-up plus stand-by energy	_____ Wh	
C. Stand-by energy	_____ Wh	
D. Energy-saver energy	_____ Wh	
E. Printing energy plus stand-by	_____ Wh	_____ Wh
F. Energy-saver delay time		
G. Recovery Energy plus Energy-Saver Energy		
Calculations, All Printers		
H. Warm-up energy, E_r [B-C]	_____ Wh	
I. Printing energy, E_p [E-C]	_____ Wh	_____ Wh
J. Recovery Energy E_{rp} [G-D]	_____ Wh	
K. Printing energy per page, E_p/n	_____ Wh	_____ Wh
$E_p/n * 0.001 =$	_____ kWh	_____ kWh
L. Energy saver time per hour [I_t-j * F]	_____ min./hr	
M. Fraction energy-saver time [L/60]	_____	
Calculations, Printers Without Auto Shut-off		
N Plug-in energy per standard month [A * 489]	_____ Wh	
O. Warm-up plus Stand-by energy per standard month [B * 20]	_____ Wh	
P. Energy-saver time per month [(M * 176)+35-(5 * F/60)]	_____ min.	
Q. Stand-by energy per standard month	_____ Wh	
[C * (211-P)]	_____ Wh	
R. Energy-saver energy per standard month [D * P]		
Calculations, Printers With Auto Shut-off		
S. Plug-in energy per standard month [A * 519]	_____ Wh	
T. Warm-up plus Stand-by energy per standard month [B * 22]	_____ Wh	
U. Energy-saver time per month [(M * 176)+3-(3 * F/60)]	_____ min.	
V. Stand-by energy per standard month [C * (179-U)]	_____ Wh	
W. Energy-saver energy per standard month [D * U]	_____ Wh	
Calculations, All Printers		
X. Machine energy per standard month--Independent at Volume E_m = [N+O+Q+R] or [S+T+V+W]	_____ Wh	
Y. Total energy per month [$E_t = E_m + (E_p/n + E_{rp})N$]		
Average total energy per page	_____ Wh	_____ Wh
Z. $E_{tave} = \dfrac{E_m + (E_p/n + E_{rp})N}{N}$	_____ Wh	_____ Wh

10.3 Calculate the data from 10.2.1 to 10.2.10 for 100 % duplexed pages and list in the appropriately designated section in Fig. 1.

11. Report

11.1 If several identical machines are rated, the average energy rating should be reported. If the results for each machine differ by more than 10 %, the test should be repeated.

11.2 All data recorded should be reported to a minimum of three significant figures.

12. Precision and Bias

12.1 Precision and bias of the energy rating may be determined with calculations, projections, extrapolations or all three, as long as the overall accuracy is not significantly affected. However, the resulting energy rating must be based upon the conditions specified in this procedure.

12.2 All time-measuring devices shall have an accuracy of ±0.5 %. All other measuring devices should provide a ±2 % accuracy.

12.3 It is not practicable to specify the precision and bias of the procedure in Test Method XXX for measuring the energy consumption of black and white personal computer printers, because there is no standard report.

IV. Test Procedure for Measuring Energy Consumption of Fax Machines.

When writing the first draft of the fax procedure, I again tried to base it as closely as possible on the copier test procedure, to make testing of equipment somewhat uniform and therefore easier. The draft included in this thesis is closely based on the copier test procedure. It is likely that this draft will change, since the technology used by fax machines, and the duty cycles they perform are very different from copiers and printers.

For this draft, I included time the fax machine might spend in an energy saver mode. To date, there are very few fax machines with an energy-saver mode, but this may change in the near future, especially if the EPA Energy Star program is expanded to include fax machines. If the fax machine does not have an energy-saver mode, users simply enter the amount of energy used in a standby mode.

The original draft tried address to some basic differences. The amount of time telephone connection services need to transmit fax data, length of telephone wire between sending and receiving machines, resolution and transmission speeds were all considerations that had to be addressed, machine protocols. Machine protocols are used between like machines that speed up the transmission and reception process. The length of the telephone wire will effect the transmission or reception speed. Also, uses of fax machines are different; in most cases they would never be turned off, so they could be on line to receive faxes.

I decided that two identical machines should be used for testing. The procedure recommends that they be connected through a simulated telephone linking system, with a specified amount of wire connecting them. Each machine should be tested for each resolution and transmission speed, and for each additional configuration. It is recommended that the user test with the machine protocol on and then off, to determine if there is a difference in energy consumption.

Generally, fax machines will never be turned off, either at night or on the weekends. This makes the need for an energy-saver mode even greater. When I brought this up at a committee meeting, one of the other members, an employee of the GSA, stated that the government required that fax machines be turned off at night and on the weekends. Therefore, users are required to test in plug-in and warm-up modes, but not required to include these values in the calculations. This way, if energy consumption in these modes is needed, users may adjust the tests to allow the calculations to include factors for these modes.

A. Changes to Draft 1.

It was suggested that there only be three different volume bands for fax machines, unlike printers and copiers, since use of the fax machine is so different than for copiers and printers. I will probably add these changes, since it will make calculations easier. Also, I found that when testing fax machines it is very difficult to obtain nominal volumes. By defining only low, medium and high volumes, testing of the fax machine will be easier.

B. Changes to Draft 2.

No significant changes were made to draft 2.

C. Changes to Draft 3.

Like the printer and copier procedures, changes were made to the third draft by changing the amount of time the fax machine will spend in the energy-saver mode. The same procedure for dealing with the energy-saver mode as a variable is used in this draft.

D. Fourth Draft of the ASTM Test Method for Fax Machines.

Draft 4 is the version that is currently under review with the ASTM committee. The meeting to discuss future changes to the fax procedure will be held in January 1994.

Fourth Draft: October 18, 1993

New Standard Test Method for Determining Energy Consumption of Facsimile Machines

Draft Version, do not quote

1. Scope

1.1 This procedure provides a test method by which facsimile machines and accessories can be rated for energy consumption.

1.2 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitation prior to use.*

2. Referenced Documents

2.1 *ASTM Standard:*

F 335 Standard Definitions of Terms Relating to Electrostatic Copying[10].

2.2 *ASTM Standard:*

F 757 Standard Test Method for Determining Energy Consumption of Copier and Copier-Duplicating Equipment[11].

3. Descriptions of Terms Specific to This Standard

3.1 For definitions of terms used in this method, see F 335 Standard Definitions of Terms Relating to Electrostatic Copying.

3.2 For definitions of terms used in this method, see F 757 Standard Test Method for Determining Energy Consumption of Copier and Copier-Duplicating Equipment.

---

[10] *Annual Book of ASTM Standards,* Vol. 15.09

[11] *Annual Book of ASTM Standards,* Vol. 15.09

3.2 For definitions of terms used in this method, see F XXX New Standard Test Method for Determining Energy Consumption of Personal Computer Printers.

3.3 *warm-up mode*--the condition that exists when the machine is turned on from a plug-in mode and prior to sending, receiving or copying.

3.4 *sending*--the machine condition that exists from the beginning to the end of the cycle that sends a page to an outside source.

3.5 *receiving*--the machine condition that exists from the beginning to the end of the cycle that receives a page from an outside source and prints that page while receiving.

3.6 *stand-by mode*--the condition that exists when the machine is not sending, receiving, or copying, has reached operating conditions, but has not yet entered into energy-saver mode.

3.7 *receiving energy*--the energy consumed during a designated receiving mode exclusive of stand-by and plug-in energy.

3.8 *sending energy*--the energy consumed during a designated sending mode exclusive of stand-by and plug-in energy.

3.9 *machine energy*--the energy consumed by a facsimile machine that is plugged-in 24 h per day and turned on 10.5 h[3] but that is not sending, receiving, or making copies.

3.10 *sending/receiving time*--the amount of time that the nominal jobs are run when testing sending and receiving energy.

3.17 *idle time*--the amount of time that the machine is not sending or receiving when testing sending or receiving energy.

3.11 *nominal facsimiles sent per day*-- the number of standard facsimiles sent on a single machine during a standard work day.

3.12 *nominal facsimiles received per day*-- the number of standard facsimiles received on a single machine during a standard work day.

3.13 *job*--receiving or sending one or more pages without interruption or delay between pages.

3.25 *cycle out*--the condition which exists when the machine has finished sending or receiving a page, and has returned to a stand-by mode.

4. Summary of Test Method

4.1 The standard energy consumption rating is determined (using a watt-hour meter) for a facsimile machine while the machine is in a simulated customer installation performing one eighth of a typical day's jobs. The typical day's jobs (size and number of pages) are based on the standard volume (see Table 1). The simulated customer installation can be calculated with actual usage data (see 4.3), or can be based on the following assumptions, that the printer will typically:

4.1.1 Be plugged in to a live power line for thirty 24 h days (720h) per month.

4.1.2 Never be turned on and off.[12]

4.1.3 Be left on 24 h per day for 30 days of each standard work month.

4.1.6 Be in an energy-saver mode some amount of time dependent on the nominal volume and use from Table 1, the sending/receiving time from Table 2, and the energy-saver delay time.

4.1.5 Perform a typical day's job each of the 30 work days each month.

4.2 The energy consumption per page or the typical month's energy consumption rating (kWh per month) are determined using calculations based on the test data.

4.3 As an alternative you can use actual usage data in these formulas. When making comparisons of like machines, it is recommended to use the same usage data.

5. Significance and Use

5.1 This test method provides a procedure for measuring the energy consumption of the product and associated accessories in various operating modes. It does not reflect the total energy required to send and/or receive a faxed page. It does not, for example, include the energy required to manufacture the paper or the machine. It is intended to permit rating the energy requirements of products by a method that will permit accurate energy efficiency comparisons of each product with all other similar products.

---

[12]Some users may want to change this if they do turn off their fax machines. Therefore, the test should be performed for the plug-in and warm-up modes, but won't necessarily be included in the calculations. If the user wants to include these modes in the calculations, the tester should recalculate the numbers used in section 10.

6. Apparatus and Supplies

6.1 *Watt-Hour Meter*, one per phase, accurate to three figures.[13]

6.2 *Timer*-- a timing device accurate to one second.

6.3 *Test Target*--A ten pitch, pica, 45 lines of lower case "k" character, 65 characters per line (2925 total characters), with a 1-in. (25-mm) clear border around the typed area, and on white paper. This target is prepared by the user. Alternatively, the ITU-TS Target #1[14] or equivalent, with 4 % coverage may be used.

6.4.1 *Paper for Plain Paper Machines*-- should be 81/2 by 11 in. (216 by 280 mm), 20-lb bond or where not applicable, use machine manufacturer's recommended mid-point range of paper weight.

6.4.2 *Paper for Other Than Plain Paper Machines*--should use manufacturer's recommended mid-point range of paper weight.

6.5 *Facsimile Machines*--two facsimile machines are to be used, one as the test sample, and a second one identical to the test sample to act as the transmitter or receiver as needed.

6.6 *PBX Line Simulator*-- A two-way telephone line simulator[15].

6.7 *Telephone wire*-- Two lengths of exactly 6 ft. should be used.

6.8 *Timer*-- a timing device accurate to one second.

---

[13]For certain low-volume copiers that consume little energy, the Duncan model EM-10 which reads to 0.1 Wh per count, or equivalent, has been found suitable for use (Section 12.2). Duncan models are available from Duncan Electric Co., Lafayette, IN, and the General Electric model is available from General Electric, Schenectady, NY.

[14]Available from the Omnicom Institute, 115 Park Street SE, Vienna, VA. ITU-TS is the International Telecommunications Union-Telecommunications Standardization Sector.

[15]The Phantom Central Office Simulator, or equivalent has been found suitable for use. The Phantom Central Office Simulator is manufactured by Command Communications Inc., in Aurora, CO. (303)750-6434, available from Fleetmasters in California (310)539-7900.

7. Sampling

7.1 The energy rating should be that for a device representative of the commercially available equipment. Any modification of the product or additional configurations that significantly alter energy consumption will require re-ratings or additional ratings.

7.3 The facsimile machine(s) to be evaluated should be set to within the manufacturers operating specifications.

7.4 If the facsimile machine has more than one rate of transmission, it should be rated for each transmission rate.

7.5 Those facsimile machines equipped with more than one resolution setting should be rated at the standard resolution setting and optionally at other resolution settings.

7.6 Optional, those facsimile machines equipped with machine proprietary transmission protocols should be tested twice, once with the proprietary transmission protocol active, and once with the proprietary transmission protocol inactive. Both image quality and energy consumption should be compared at each protocol setting so optimal settings may be determined.

8. Preparation of Apparatus

8.1 *Test Conditions:*

8.1.1 The room ambient shall be within a range of 21 ±3° C; 40 to 60 % relative humidity.

8.1.2 The working voltage shall be machine-rated voltage ±2 %.

8.1.3 Both machines shall be at least 2 ft (610 mm) from any wall or air obstacle.

8.1.4 All supplies used shall be those specified by the facsimile machine manufacturer and preconditioned for a minimum of 24 h at the room ambient temperature and humidity prior to evaluating the facsimile machine energy rating.

8.1.5 AC power shall be supplied as a true sine wave with no more than 3 % harmonic distortion.

8.1.6 The power frequency must be rated frequency ±0.1 Hz.

8.1.7 The manufacturer will define the configuration (including accessories) of the machine to be tested and the volume at which it will be rated (Table 1). Normally, each facsimile machine will be rated for the standard volumes for which the manufacturer intends to market the product.

8.1.8 When operator speed is a variable affecting energy use the manufacturer should use and specify a normal operating time.

NOTE--During the test cycle, the machine should be allowed to cycle out after the required number of pages have been sent or received. This aspect does not apply to those machines having automatic document feeders or other features that allow for continuous operation without cycling out.

Example: Document change time used--3.0 s

TABLE IV.1 Nominal Parameters for Each Standard Volume

Nominal Monthly Volume, Pages per Month	Nominal Day's Pages	Nominal Jobs (1/8 day)n[A]		
		Number of Jobs	Number of Pages per Job	Job Interval
200	8	1	1	60 min.
500	24	3	1	20 min.
1 000	48	3	2	20 min.
2 500	112	7	2	8.6 min.
5 000	224	14	2	8.6 min.
10 000	432	18	3	3.3 min.
25 000	1 152	36	4	1.6 min.
40 000	1 824	57	4	62 sec

[A] n = number of jobs * number of originals * number of pages per original

TABLE IV.2 Calculation for Sending/Receiving Time

Nominal Monthly Volume, Pages per Month	Number of Jobs (*j*)	Number of Pages per Job	Sending/Receiving Time Minutes per Hour (S/R_t)
200	1	1	1/X[B]
500	3	1	3/X
1 000	3	2	3/X+3/Y[C]
2 500	7	2	7/X+14/Y
5 000	14	2	14/X+14/Y
10 000	18	3	18/X+36/Y
25 000	36	4	36/X+108/Y
40 000	57	4	57/X+171/Y

[B] X = machine speed, first page

[C] Y = machine speed, multi page

8.1.9 The test should be discontinued if an unusually high number of machine problems occur. Excess machine stoppages may distort the overall energy rating. A reasonable number of paper jams that can be readily cleared by the operator should not be considered reason to discontinue the test.

9. Procedure

9.1 Steps 9.1.1, 9.1.2, 9.1.3 and 9.1.4 of this procedure should be completed once for each test machine. The data from 9.1.1, 9.1.2, 9.1.3 and 9.1.4 will apply to all standard volumes for which the machine is being rated. The data from 9.1.5 will only apply to one configuration, one resolution, and one combination of rates of transmission, and must be repeated for all other configurations, resolutions, and combinations of rates of transmission for which the machine is being rated. Prior to the start of this test, the machine should be plugged in to a live power line, turned on and stabilized at room ambient conditions for at least 12 h. Using the PBX line simulator and telephone wire, interconnect the test machine and its duplicate in such a way that they can send and receive facsimile messages between them. This should be done at least 12 hours prior to the test. An appropriate watt-hour meter should be in line with the machine, ready to give an accurate indication of machine energy consumption without disruption of the energy source.

9.1.1 *Sending/Receiving Time*--Choose the appropriate formula in Table 2 that matches the monthly volume for which the machine is being rated. Using the manufacturer's values for fax transmission speeds, where X is the number of pages sent or received per minute for the first page, and Y is the number of pages sent or received per minute for multiple pages, follow the appropriate formulas. Do the calculations twice, once for the sending time, and once for the receiving time. Add the two values together, then divide by two and record the sending/receiving time in Figure 1.

9.1.1 *Plug-In Mode Energy*--Read and record the watt-hour meter indication and the time (or start the stop watch or timer). After 1 h, read and record the watt-hour indication again. The difference between the two readings of the watt-hour meter is the observed data for plug-in mode energy use. Record the result in Fig. 1, Test Results Part A. If it is known that the test machine consumes no energy during the plug-in mode, or that the machine is never turned off, enter a zero for the observed data for plug-in energy use and omit this step. Also see footnote 3.

9.1.2 *Warm-Up Mode Plus Stand-By Mode Energy*--With the machine in a stabilized plug-in mode, read and record the watt-hour meter indication and the time (or start the stopwatch or timer). Turn the machine on and allow the machine to warm up and stabilize in the ready mode. After 1 hr, read and record the watt-hour indication again. The difference between the two readings of the watt-hour meter is the observed data for warm-up mode plus stand-by mode energy use. Record the result in Fig. 1, Test Results Part B. If it is known that the machine uses no energy in the warm-up mode (as defined by this procedure), or that the machine is never turned off, omit this step and proceed to 9.1.3. Also see footnote 3.

9.1.3 *Standby Mode Energy Mode*---For facsimile machines having an energy-saver mode feature, disable the energy-saver mode. At the conclusion of the previous 1 h measurement (9.1.2) leave the machine turned on. After 1 h, record the watt-hour reading. The difference between the watt-hour reading at the start and finish of the hour is the observed data for stand-by mode energy. Record the result in Fig. 1, Test Results Part C.

9.1.4 *Energy-Saver Mode Energy* --For facsimile machines having an energy saver mode feature, enable the energy saver mode. If the energy-saver mode is automatic, let machine enter energy-saver mode. When it has entered energy-saver mode, read and record the watt-hour meter and the time. After 1 h, record the watt-hour reading again. The difference between the watt-hour reading at the start and finish of the hour is the observed data for energy-saver mode energy. Record the result in Fig. 1, Test Results Part D. If it is known that the machine does not have an energy-saver mode (as defined by this procedure) record the stand-by energy (results from Part C) in Fig. 1, Test Results Part D.

9.1.5 *Energy-Saver Delay Time*--For machines having an energy-saver mode feature, if the time to enter the energy-saver mode is adjustable, set it to one minute. Send a page. Using the timer, record the amount of time it takes the machine to enter an energy-saver mode. Record the time in minutes and seconds. If the machine is one which is manually placed in the energy-saver mode, activate the energy saver switch when the machine has cycled out, and then record the time it takes to reach the energy saver mode. The machine should stay in the energy-saver mode for 1 hour. Using the timer, record the amount of time it takes the machine to come out of the energy-saver mode, in minutes and seconds. Add this time to the amount of time it took the machine to go into an energy-saver mode and record the result in Fig. 1, Test Results Part E.

9.1.6 *Sending Mode Energy Plus Stand-by Mode Energy*--With the machine in a stand-by mode, read and record the watt-hour indication and the time (or start the stopwatch or timer). Using a standard original(s) (6.2) have the test machine send the standard jobs (Table 1) to the duplicate machine for the standard volume and configuration, resolution or rate of transmission for which the machine is being rated. Equally space the jobs throughout the 1 h allocated for this part of the test (Table 1 for job time interval). The operator should send the original image in such a manner as to have a minimal impact on job time and energy use (see 8.1.8 for exceptions). After the jobs have been performed and 1 h has elapsed, read and record the watt-hour meter indication again. The difference between the two readings of the watt-hour meter is the observed data for sending energy use. Record the result in Fig. 1, Test Results Part F.

9.1.7 *Receiving Mode Energy Plus Stand-by Mode Energy*--With the machine in a stand-by mode, read and record the watt-hour indication and the time (or start the stopwatch or timer). Using a standard original(s) (6.2) have a duplicate machine send the standard jobs (Table 1) to the test machine for the standard volume and configuration, resolution or rate of transmission for which the machine is being rated. Equally space the jobs throughout the 1 h allocated for this part of the test (Table 1 for job time interval). The operator should send the original image in such a manner as to have a minimal impact on job time and energy use (see 8.1.8 for exceptions). After the jobs have been performed and 1 h has elapsed, read and record the watt-hour meter indication again. The difference between the two readings of the watt-hour meter is the observed data for receiving energy use. Record the result in Fig. 1, Test Results Part G.

9.1.8 *Recovery Energy plus Energy-Saver Energy*--Repeat the steps in 9.1.5, when the machine enters the energy-saver mode, read and record the watt-hour indication and the time (or start the stopwatch or timer). At one hour minus the time needed for the machine to come out of the energy-saver mode, bring the machine out of the energy-saver mode. When the machine reaches the stand-by mode, the time should show one hour. Record the watt-hour meter reading. The difference between these two readings is the Recovery Energy plus Energy-Saver Energy. Record this in Figure 1, Part H.

10. Calculation

10.1 Enter the number of pages n (Table 1, Footnote A) and the monthly volume N [$n * 176$] into Fig. 1.

10.2 Calculate the data from the following sections and list in the appropriately designated section in Fig. 1. Also see 4.3.

10.2.1 Enter the data obtained from step 9.2.1 under Sending/Receiving Time, S/R_t in Fig. 1.

10.2.2 Enter the data obtained from steps 9.1.2, 9.1.3, 9.1.4, 9.1.5, 9.1.6 and 9.1.7 under Test Results, Parts A, B, C, D, E, F, G and H.

10.2.3 Calculate sending energy E_s using [F - C] and record under Part J.
10.2.4 Calculate receiving energy E_r using [G - C] and record under Part K.

10.2.5 Calculate sending energy per page (E_s/n). Record under Part L.

10.2.6 Calculate receiving energy per page (E_r/n). Record under Part M.

10.2.7 Calculate recovery energy (E_{rf}). Record under Part N

10.2.7 For facsimile machines having an energy saver mode feature, calculate the energy-saver time per hour. Multiply the number of jobs j by the energy saver delay time, and subtract the total from the idle time I_t. ($I_t - j * E$). If this value is less than zero, enter zero. Record under Part O.

10.2.8 For facsimile machines having an energy saver mode feature, calculate the fraction of energy-saver time. Divide the energy-saver time per hour by 60 minutes per hour (O/60). Record under Part P.

10.2.9 For fax machines with an energy-saver mode feature, calculate the amount of time a copier without an auto shut-off is in an energy-saver mode per month: ((P * 176) + 35 - (5 * E/60)). Record this result under Part S.

10.2.10 For fax machines without an auto shut-off mode, calculate stand-by energy per standard month (C * (211-S) h/month) and record under Part T.

10.2.11 For facsimile machines having an energy saver mode feature, and no auto shut-off mode, calculate energy-saver energy per standard month (D * S h/month). Record under Part U.

10.2.12 For fax machines with an energy-saver mode feature, calculate the amount of time a fax machine with an auto shut-off mode is in an energy-saver mode per month ((P * 176)+35-(3 * E/60)). Record this result under Part X.

10.2.13 For fax machines with an auto shut-off mode, calculate stand-by energy per standard month (C * (211-X) h/month) and record under Part Y.

10.2.14 For facsimile machines having an energy saver mode feature, and an auto shut-off mode, calculate energy-saver energy per standard month (D * X h/month). Record under Part Z.

FIG. IV.1 Sample Data Sheet

Machine Tested ____

Monthly volume *N* (*n* * 176)		_____
Number of pages *n* in test (from Table 1)		_____
Sending/Receiving Time S/R_t (from Table 2)		_____ min.
Idle Time, I_t [60 minutes - S/R_t]		_____ min.
Number of Jobs *j* in test (from Table 1)		_____
Test Results (1 h Tests)		
A.	Plug-in energy	_____ Wh
B.	Warm-up plus Stand-by energy	_____ Wh
C.	Stand-by energy	_____ Wh
D.	Energy-saver energy	_____ Wh
E.	Energy-saver delay time	_____ min.
F.	Sending energy plus Stand-by energy	_____ Wh
G.	Receiving energy plus Stand-by energy	_____ Wh
H.	Recovery plus Stand-by energy	
Calculations, All Fax Machines		
I.	Warm-up energy, E_r [B - C]	_____ Wh
J.	Sending energy, E_s [F - C]	_____ Wh
K.	Receiving energy, E_r [G - C]	_____ Wh
L.	Recovery energy, E_{rf} [H - E]	_____ Wh
M.	Sending energy per page, E_s/n	_____ Wh
N.	Receiving energy per page, E_r/n	_____ min./hr
O.	Energy saver time per hour [I_t - *j* * E]	_____
P.	Fraction energy-saver time [O/60]	
Calculations, Fax Machines Without Auto Shut-off		
Q.	Plug-in energy per standard month [A * 489]	_____ Wh
R.	Warm-up plus Stand-by energy per standard month [B * 20]	_____ Wh
S.	Energy-saver time per month [(P * 176)+35-(5 * E/60)]	_____ min.
T.	Stand-by energy per standard month [C * (211-S)]	_____ Wh
U.	Energy-saver energy per standard month [D * S]	_____ Wh
Calculations, Machines With Auto Shut-off		
V.	Plug-in energy per standard month [A * 519]	_____ Wh
W.	Warm-up plus Stand-by energy per standard month [B * 22]	_____ Wh
X.	Energy-saver time per month [(PX 176)+3-(3 * E/60)]	_____ min.
Y.	Stand-by energy per standard month [C * (179 - X)]	_____ Wh _____ Wh
Z.	Energy-saver energy per standard month [D * X]	

Calculations, All Fax Machines

AA. Machine energy per standard month--Independent at Volume E_m = [T+U] or [Y+Z] _____ Wh

BB. Sending energy per standard month (M/n) *N

CC. Receiving energy per standard month (N/n) *N _____ Wh

DD. Recovery Energy per standard month (L/n) *N _____ Wh

EE. Total energy per month E_t = AA + BB + CC + DD _____ Wh

FF. Average total energy per page

$$E_{tave} = \frac{(AA + BB + CC + DD)}{N}$$

10.2.15 Calculate machine energy per standard month E_m = [L+T+U] or [L+Y+Z]. This is the energy consumed by the machine independent of volume. Record this result under Part AA.

10.2.16 Calculate the sending energy per standard month E_s [(F/n)N]. Record this result under Part BB.

10.2.17 Calculate the receiving energy per standard month E_r [(G/n)N]. Record this result under Part CC.

10.2.18 Calculate the total energy per month E_t. Total energy equals machine energy plus sending energy plus receiving energy.

$$E_t = AA + BB + CC + DD$$

Record the result under EE.

10.2.19 Calculate the average total energy per page as follows:

$$E_{tave} = \frac{(AA + BB + CC + DD)}{N}$$

Record under FF.

11. Report

11.1 If several identical machines are rated, the average energy rating should be reported. If the results for each machine differ by more than 10 %, the test should be repeated.

11.2 All data recorded should be reported to a minimum of three significant figures.

12. Precision and Bias

12.1 Precision and bias of the energy rating may be determined with calculations, projections, extrapolations or all three, as long as the overall accuracy is not significantly affected. However, the resulting energy rating must be based upon the conditions specified in this procedure.

12.2 All time-measuring devices shall have an accuracy of ±0.5 %. All other measuring devices should provide a ±2 % accuracy.

12.3 It is not practicable to specify the precision and bias of the procedure in Test Method F XXX for measuring the energy consumption of facsimile equipment, because there is no standard report.

V. Test Procedure for Measuring the Energy Consumption of Personal Computers.

Since the ASTM F05 committee responsible for the review of the fax, copier and printer test methods is only for imaging products, this test procedure is not under review by an ASTM committee. I am currently looking into the possibility of expanding the scope of the F05 committee to include personal computers. Alternately, there may be another ASTM committee that could become responsible for this test procedure. However, since energy consumption test methods for other office equipment is under the responsibility of the F05 committee, I feel the method should stay within this committee. The format of the ASTM test procedures was followed as closely as possible to provide users a similar, and possibly more familiar method for testing personal computers.

There are many areas of uncertainty that could effect the testing of personal computers. Productivity and how it is affected by energy saving modes of a computer can certainly become an issue. For example, if the computer takes more than a few seconds to come to a ready state after being in a power management mode, users must wait unnecessarily to begin work. By using this test procedure only as a comparative standard, we avoid difficulties associated with productivity. We believe it is up to the manufacturer to address these issues when marketing the computer; users are capable of making their choice according to their own preferences, including both energy consumption of the machine, and areas that may effect their productivity.

As discussed in Chapter 3, there are statistical data available for the hours of use of personal computers (Tiller 1992). These were used when determining the plug-in and warm-up hours, the energy saving mode hours (suspend and standby), and the ready and operating mode hours. Testing for each mode is over an hour period, with plug-in, warm-up, and ready mode tested in a way identical to the ASTM test procedures. In this case, ready mode for computers is similar to standby mode for copiers. It is the mode where no energy saving functions are in effect, but the computer is not in active use. The operating mode energy is tested for an hour, with the procedure outlined in section IV.A.8.1. See Table 4.1 for details.

Table 4.1. Modes Used for Calculating Energy Consumption for Office Equipment

	Plug-in (PI)	Warm-up (WU)	Idle (listed)	Power Management (listed)	Operating (listed)
Copiers	PI	WU	Standby	Energy-Saver	Copying
Printers	PI	WU	Standby	Energy-Saver	Printing
Fax Machines			Standby	Energy-Saver	Sending/Receiving
Personal Computers	PI	WU	Ready	Standby, Suspend	Operating

This procedure assumes that most computer users will use a word processing program, a spreadsheet program, and a graphics program most often. It does not intend to imply that other programs will not be used by a particular computer. Since this test procedure will be used as a basis for comparison, and not to test actual energy consumption, a standard method for testing the operating mode energy is what is needed. While an argument can be made that the computer should be tested with other types of programs, it was thought that using these for the standard usage cycle was sufficient. The standby and suspend modes are also tested for an hour, in varying states of power management, as defined in section 2. The definitions for this method are different than those for the ASTM methods, since we followed the industry standard definitions.

Following is the first draft of the test procedure for computers. It is by no means a final draft, as this has not yet been put up for review. It is expected to be used eventually in COPEE's testing and information program.

A. First Draft for the Test Method for Personal Computers.

Proposed Interim Method for
Determining Energy Use
of Personal Computers

First Draft
December 15, 1993

1. Scope

1.1 This procedure provides a test method by which personal computers used in general-purpose office applications can be rated for energy consumption.

1.2 This standard does not purport to address all of the safety problems, if any associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitation prior to use.

1.3 This standard does not purport to address other performance characteristics of PCs that may be related to energy use, such as power quality (power factor, total harmonic distortion) and electromagnetic radiation.

2. Descriptions of Terms Specific to This Standard

2.1 Personal computer (PC) - a programmable electronic calculating device designed primarily for a single user and capable of running general-purpose office applications software, such as word processing, electronic mail, spreadsheets, data bases, and other programs for the statistical analysis and presentation of data in graphs or tables. A PC is assumed to include a keyboard or other means for the individual user to input data. Excluded are special-purpose machines built with PC-type CPU chips, smart terminals and workstations serving multiple terminals. (ASTM: A programmable electronic desk top calculating device).

2.2 Computer display - a video screen or other electronic display that allows the user to interact with the computer by viewing characters, symbols, or other images.

2.3 Ready mode[16] - The condition that exists when the computer system is fully powered up and ready for use.

2.4 Operating mode - The condition that exists when the computer system is fully powered up and in use.

2.5 Standby mode - The condition that exists when the machine is in an intermediate system dependent state which is consuming less power than when the machine is in a ready mode. This is a state of minimal power reduction, where the transition from standby to ready provides a barely noticeable time delay. To activate this mode, the central processing unit must be idle and no device activity will occur within a machine defined period of time.

2.6 Suspend mode - The condition that exists when the machine is using the lowest level of power consumption available which preserves operational data and parameters. The machine must go back to the ready mode when normal activity is resumed. Resumption of activity occurs when signaled by an external event. In some cases, this mode is referred to as the sleep mode.

2.7 Power Management mode - Either a Standby or Suspend mode.

2.8 Plug-in mode - The condition that exists when the machine is plugged in to an appropriate electrical source and is not turned on for use.

---

[16]Definitions of the four operating states are taken, verbatim, from the Intel/Microsoft Advanced Power Management specification, version 1.0. These definitions have been adopted, as closely as possible by the Video Electronics Standards Association (VESA) for its display power management activities; modifications for displays are included here.

2.9 Standard month - thirty 24-h days.

2.10 Standard work day - 10.5 h.

2.11 Standard work month - 22 standard work days.

2.12 Accessories - anything added to the computer system which is beyond the standard configuration, as specified by the manufacturer.

2.13 Job - Running a program or using the computer without interruption or delay.

3. Summary of Test Method

3.1 The standard energy consumption rating is determined (using a watt-hour meter) for a personal computer while the machine is in a simulated customer installation performing a typical job but of continuous use over an hour period. The simulated customer installation can be calculated with actual usage data, or can be based on the following assumptions, that the PC will typically:

3.1.2 Be connected to a live power line for thirty 24 h days (720h) per month.

3.1.3 Be turned on or off or both each of 22 days per month.

3.1.4 Be left on 24 h per day for 5 days of each standard work month.

3.1.5 Be in a warm-up mode for 17 hours per month.

3.1.6 Be on for an average of 12 h each of the 22 days.

3.1.7 Be in an operating mode for 15 % of the 12 hours per day it is on each of 22 days. It will be in operating mode for 39.6 hours per month.

3.1.8 Be in either a standby, suspend or ready mode for some percentage of the 12 hours per day it is on each of the 22 days, depending on the delay time for the power management mode.

3.1.9 Be in a plug-in mode for 439 hours per month.

3.1.10 Perform a typical day's jobs each of the 22 work days each month.

3.2 The typical month's energy consumption rating (kWh per month) are determined using calculations based on the test data.

3.3 As an alternative actual usage data for estimated hours of use in these formulas can be used. When making comparisons of like machines, it is recommended to use the same usage data.

4. Significance and Use

4.1 This test method provides a procedure for measuring the energy consumption of the product in various operating modes. It does not reflect the total energy required to use the machine. It does not, for example, include the energy required to manufacture the machine. It is intended to permit rating the energy requirements of products by a method that will permit accurate energy efficiency comparisons of each product with all other similar products.

5. Apparatus and Supplies

5.1 Watt-hour meter - one per phase, accurate to three figures.
5.2 Timer - a timing device accurate to one second.

6. Sampling

6.1 The energy rating should be that for a device representative of the commercially available equipment. Any modification of the product or additional configurations that significantly alter energy consumption will require re-rating or additional ratings. The tester must specify the configuration of the machine, including type of CPU and clock speed, size of memory (RAM), size and number of floppy disk and hard disk drives.

6.2 The PC(s) to be evaluated should be set to within the manufacturers operating specifications.

7. Preparation of Apparatus

7.1 Test Conditions:

7.1.1 The room ambient shall be within a range of 21 ± 3°C; 40 to 60 % relative humidity.

7.1.2 The working voltage shall be machine-rated voltage ± 2 %.

7.1.3 The machine shall be at least 610 mm (2 ft) from any wall or air obstacle.

7.1.4 All supplies used shall be those specified by the PC manufacturer and preconditioned for a minimum of 24 h at the room ambient temperature prior to evaluating the PC energy rating.

7.1.5 AC power shall be supplied as a true sine wave with no more than 3 % harmonic distortion.

7.1.6 The power frequency must be rated frequency ±0.1 Hz.

7.1.7 The manufacturer will define the configuration of the machine to be tested, the standard configuration at which it will be rated (Section 8.1). Normally, each PC will be rated for the standard configuration for which the manufacturer intends to market the product.

7.1.8 When operator speed is a variable affecting energy use the manufacturer should use and specify a normal operating time.

8. Procedure

8.1 Calculation of Operating Mode:

To perform the following test, the monitor should be connected to the CPU, but the power plug from the monitor should be plugged into a live power line separately from the CPU. If the PC being tested is a combination monitor/CPU unit, Test Method XXX should be followed.

8.1.1 Open the word processing program.

8.1.2 When program is open, type continuously at 100 keystrokes per minute, the letter k, for 23 minutes.

8.1.3 Save the document as TEST1.

8.1.4 Close the word processing program.

8.1.5 Open the spreadsheet program.

8.1.6 When program is open, type two sevens into a cell of the worksheet.

8.1.7 Enter the two sevens, go to the next cell of the worksheet.

8.1.8 Repeat steps and , typing continuously at 90 keystrokes per minute for 23 minutes.

8.1.9 Save the document as TEST2.

8.1.10 Close the spreadsheet program.

8.1.11 Open the graphics program.

8.1.12 Draw circles with the graphics program continuously for 8 minutes, drawing 30 circles per minute.

8.1.13 Save document as TEST3.

8.1.14 Close the graphics program.

8.1.15 One minute should be allotted to saving a document, and to both opening and closing a document. If more time is needed for saving or opening and closing a document, the six minute interval should be divided to suit the time needed for each portion of the job. If the time needed to test the machine in the operating mode is effected when the unit has power management features turned on (see section 8.2.6), the machine may not be tested with power management features turned on.

8.2 Each of the following steps should be completed once for each test machine. The data for the ready mode energy will only apply to one configuration and must be repeated for all other configurations for which the machine is being rated. Prior to the start of this test, for PCs having power management mode features, set any power management options to maximum performance, with standard processing speed, and any power saving features such as screen dimming turned off. The machine should be plugged in to a live power line but turned off and stabilized at room ambient conditions for at least 12 h prior to the start of the test. An appropriate watt-hour meter should be in line with the machine, ready to give an accurate indication of machine energy consumption without disruption of the energy source.

8.2.1 Plug-in Mode Energy - Read and record the watt-hour meter indication and the time (or start the stop watch or timer). After 1 h, read and record the watt-hour indication again. The difference between the two readings of the watt-hour meter is the observed data for plug-in mode energy use. Record the result. If it is known that the test machine consumes no energy during the plug-in mode, enter a zero for the observed data for plug-in energy use and omit this step. Record the result in Fig. 1, Test Results Part A.

8.2.2 Warm-up Mode Energy Plus Read Mode Energy - With the machine in a stabilized plug-in mode, read and record the watt-hour meter indication and the time (or start the stopwatch or timer). Turn the machine on and allow the machine to warm up and stabilize in the ready mode. After 1 hr, read and record the watt-hour indication again. The difference between the two readings of the watt-hour meter is the observed data for warm-up mode plus stand-by mode energy use. Record the result in Fig. 1, Test Results Part . If it is known that the machine uses no energy in the warm-up mode (as defined by this procedure) omit this step and proceed to 9.1.3. Record the result in Fig. 1, Test Results Part B.

8.2.3 Ready Mode Energy - At the conclusion of the previous 1 h measurement (8.1.2) leave the machine turned on. After 1 h, record the watt-hour reading. The difference between the watt-hour reading at the start and finish of the hour is the observed data for ready mode energy. Record the result in Fig. 1, Test Results Part C.

8.2.4 Standby Mode Energy - For PCs having a standby mode feature, set any power management options to maximum conservation, minimal processing speed, and with any power saving features such as screen dimming turned on. Enable the standby mode, or if the standby mode is automatic, let the machine enter the standby mode. When it has entered the standby mode, read and record the watt-hour meter and the time. After 1 h, record the watt-hour reading again. The difference between the watt-hour reading at the start and finish of the hour is the observed data for standby mode energy. If it is known that the machine does not have a standby mode (as defined by this procedure) record the operating mode energy. Record the result in Fig. 1, Test Results Part D.

8.2.5 Suspend Mode Energy - For PCs having a suspend mode feature, enable the suspend mode, or if the suspend mode is automatic, let the machine enter the suspend mode. When it has entered the suspend mode, read and record the watt-hour meter and the time. After 1 h, record the watt-hour reading again. The difference between the watt-hour reading at the start and finish of the hour is the observed data for standby mode energy. If it is known that the machine does not have a suspend mode (as defined by this procedure) record the standby mode energy, or if the machine does not have a standby mode, record the operating mode energy. Record the result in Fig. 1, Test Results Part E.

8.2.6 Minimum Operating Mode Energy - For PCs having power management mode features, set any power management options to maximum conservation, minimal processing speed, and with any power saving features such as screen dimming turned on. Read and record the watt-hour meter indication and the time (or start the stopwatch or timer). Follow the calculations in 8.1, and record the operating mode energy. Record the result in Fig. 1, Test Results Part F.

8.2.7 Maximum Operating Mode Energy - For PCs having power management mode features, set any power management options to maximum performance, with standard processing speed, and any power saving features such as screen dimming turned off. Read and record the watt-hour meter indication and the time (or start the stopwatch or timer). Follow the calculations in 8.1, and record the operating mode energy. Record the result in Fig. 1, Test Results Part G.

8.2.8 Standby Mode Delay Time - For PCs having a suspend mode, if the time to enter the mode is adjustable, set it to maximum conservation, with reduced (minimized) processing speed and any power saving features such as screen dimming turned on (maximized). Open and close a word processing program. Using the timer, record the amount of time it takes the machine to enter suspend mode. If the machine is one which is manually placed in the standby mode, activate the standby mode after opening and closing a word processing program, and record the time it takes to reach the standby mode. Record the time in minutes and seconds in Figure 1.

8.2.9 Suspend Mode Delay Time - For PCs having a suspend mode, put the machine in standby, have the machine enter standby automatically, or if the machine does not have a standby mode but does have a suspend mode, open and close a word processing program. Using the timer, record the amount of time it takes the machine to enter a suspend mode. If the machine is one which is manually placed in the suspend mode, activate the suspend mode after the machine is either already in a standby mode, or if there is no standby mode, after opening and closing a word processing program. Record the time it takes to reach the suspend mode. Record the time in minutes and seconds in Figure 1.

Table V.1

Minutes to Power Management (Standby or Idle)	% Power Managed	Ready Time Percentage (No Power Management)
1	85%	0
2	83%	3%
3	80%	5%
4	77%	8%
5	75%	10%
6	73%	12%
7	71%	14%
8	69%	16%
9	68%	18%
10	66%	19%
15	60%	25%
20	55%	30%
25	51%	34%
30	47%	38%
35	43%	42%
40	40%	45%
45	37%	48%
60	30%	55%
75	25%	60%
90	21%	64%
120	17%	68%
180	11%	74%
720	0%	85%

9. Calculations

9.1.1 Enter the Standby Delay Time and Suspend Delay Time from sections 8.2.5 and 8.2.6 in Figure 1.

9.1.2 Enter the data obtained from steps 8.2.1, 8.2.2, 8.2.3, 8.3.4, 8.3.5, 8.2.6 and 8.2.7 in Figure 1, parts A, B, C, D, E, F and G.

9.1.3 Using the amount of time it takes the computer to go into an standby mode (Figure 1 and standby delay time), and Table 1, record the percentage of time the machine is in a ready mode.

9.1.4 Using the standby delay time and Table 1, record the percentage of time the machine could be in a standby mode.

9.1.5 Using the suspend delay time and Table 1, record the percentage of time the machine could be in an suspend mode.

9.1.6 Multiply the percentage ready time by 264 (12 hours per day, times 22 days per month).

9.1.7 Subtract the percentage ready time from percentage suspend time. Multiply this number by 264. If this value is less than zero, enter zero.

9.1.8 Subtract the percentage ready time and the percentage suspend time from the percentage standby time. Multiply this number by 264.

9.1.9 Calculate the minimum operating energy per standard month. Multiply F by 39.6 hours/month.

9.1.10 Calculate the maximum operating energy per standard month. Multiply G by 39.6 hours/month.

9.1.11 Calculate the plug-in energy per standard month. Multiply A by 439.

9.1.12 Calculate the warm-up energy per standard month. Multiply B by 17.

9.1.13 Calculate the ready energy per standard month. Multiply C by

9.1.14 Calculate the standby energy per standard month. Multiply D by

9.1.15 Calculate the suspend energy per standard month. Multiply E by

9.1.16 Calculate machine energy per standard month $E_m =$. This is the energy consumed by the machine independent of operation. Record this result under Part .

FIG. V.1 Sample Data Sheet

Machine Tested ____

Suspend Delay Time		_____ min.
Standby Delay Time		_____ min.
A.	Plug-in energy	_____ Wh
B.	Warm-up plus Ready energy	_____ Wh
C.	Ready energy	_____ Wh
D.	Standby energy	_____ Wh
E.	Suspend energy	_____ Wh
F.	Minimum operating energy	_____ Wh
G.	Maximum operating energy	_____ Wh
Calculations, All Computers		
H.	Ready Time percentage	_____ %
I.	Standby Time percentage	_____ %
J.	Suspend Time percentage	_____ %
K.	Ready Time per month	_____
L	Standby Time per month	_____
M.	Suspend Time per month	_____
N.	Minimum Operating energy, E_{o-} [F * 39.6]	_____ Wh
O.	Maximum Operating energy, E_{o+} [G * 39.6]	
P.	Plug-in energy per standard month [A * 439]	_____ Wh
Q.	Warm-up plus Stand-by energy per standard month [B * 17]	_____ Wh
R.	Ready energy per standard month [C * J]	
S.	Stand-by energy per standard month [D * K]	_____ Wh
T.	Suspend energy per standard month [E * L]	_____ Wh
U.	Machine energy per standard month--Independent of tests E_m = [N + O + P + Q + R]	_____ Wh
V.	Total minimum energy per month [S + F] $E_{t-} = E_m + E_{o-}$	_____ Wh
	Total maximum energy per month [S + G] $E_{t+} = E_m + E_{o+}$	

9.1.17 Calculate the total minimum energy per month E_t. Total energy equals machine energy plus operating energy.

$$E_{t-} = E_m + E_{o-}$$

9.1.18 Calculate the total maximum energy per month E_t. Total energy equals machine energy plus operating energy.

$$E_{t+} = E_m + E_{o+}$$

Chapter 5: Office Equipment Operating Profiles and Their Influence on Energy Use

I. Introduction

In the previous chapter, test procedures for testing energy consumption of some electronic office equipment were presented. From these test procedures, we can obtain both the energy usage and the power drawn from equipment. However, energy usage of a machine depends on both usage patterns and the ability of the machine to track that usage via power management. Measurements of energy alone give the net effect of both of these factors together, but it is necessary to separate them to assess the potential of power management for stand-alone or networked computers and peripherals.

For virtually all existing desktop computers, electric power is nearly constant and power measurements alone do not reveal operating profiles. As mentioned in previous chapters, the National Research Council (Tiller 1992) of Canada has developed software that can be installed in a personal computer to record activity as measured by keystrokes. This software has been used by NRC in about 150 computers.

For imaging technologies, power usage provides strong but unreliable clues about equipment usage. There is a need for more widely practiced power monitoring, for less expensive monitoring, and for consideration of approaches that record information provided from the machine as a more direct indication of operating profiles.

For this chapter, I measured a variety of different copiers and printers, in Europe and the United States. I tested the machines with a watt-hour meter, which gave me a printout of both energy and power, every 15 minutes. From these data, I compared the actual energy use of the machines to predicted usage using both measured operating profiles and the ASTM test procedures.

II. Methods for Monitoring Operating Profiles of Copiers, Printers and Fax Machines

A. Monitoring Copier Activity by Recording Light Pulses

Copiers optically record the image to be reproduced. Most copiers use a lamp to illuminate the image and focus the light onto a photosensitive drum to which toner adheres. In this case, the lamp is flashed once for each reproduced image and a count of the pulses of light provides an exact measure of copier usage. Such a technique would not work for digital copiers that scan an image, record it digitally, and make multiple copies from the digital image.

Relatively low-cost, stand-alone data loggers to record light pulses have been developed in response to substantial efforts sponsored by electric utilities to measure the benefits of lighting retrofit programs. These loggers measure operating profiles for lights by recording the transitions from lower to higher levels of light and back to lower levels.

The meter we selected is made by Pacific Science and Technology (PS&T). It measures 2.5 x 5 x 10 cm (1" x 2" x 4") and is operated by a lithium battery. The photosensitive element, normally mounted flush within the meter case, is equipped with an adjustable gain to vary the threshold at which the meter is triggered and records a pulse. It can log light pulses at intervals as short as one second in duration and the time at which these light pulses occurred. Data are transferred out of the logger by connecting it to a special device and then to a personal computer which utilizes the company's customized software. The data can be transferred to spreadsheet programs for analysis.

It is necessary to install the meter on a copier in a way that does not interfere with normal usage of the machine. We initially verified that the meter was suitable by mounting a piece of fiber optic on the copying surface of a light-duty office copier to accept the light pulses from the copier's lamp. The rear end of the fiber was placed at the meter's photosensor. At our suggestion, PS&T removed the photosensor from its case and connected it by wires, allowing the sensor to be placed on the copying surface and the meter adhered unobtrusively to the copier body. In addition, the company modified the software to permit the meter to record as many as 80 pulses per minute, a feature important for monitoring high-speed copiers.

This meter has proved to work well. It indicates via an LED when it has received a pulse and this indication matched copier operation we observed in limited testing on both low and high speed copiers. As a single piece with added engineering to separate the light sensor and increase the speed, it was sold to us for about $350.

B. Monitoring Fax Machine Activity with Printed Log Sheets

A fax machine electronically tracks the number of pages sent and received per day. Some fax machines allow the user to print out transmission and/or reception journals that give the total number of faxes transmitted or received and also the date, time, duration, number of pages, phone number and status of particular transmitted or received faxes.

Not all fax machines automatically print both a journal of received and transmitted pages. However, all machine surveyed in this report had an option to print the journal. Following is an example of a fax machine transmittal/reception journal.

Table 5.1. Fax Transmission/Reception Journal.

Date	Time	Duration min: sec.	Pages Sent or Received (S or R)
3 Nov.	6:00	00:54	1 S
3 Nov.	6:20	00:48	1 R
3 Nov.	12:52	01:32	2 S
3 Nov.	14:35	03:21	5 R
3 Nov.	15:00	00:57	1 R
3 Nov.	15:06	01:18	2 R
3 Nov.	16:29	01:12	1 R
3 Nov.	18:32	00:53	1 S
3 Nov.	20:52	03:02	4 R

C. Monitoring Printer Activity by Recording Number of Pages Printed per Day

When some printers are first turned on, a page can be printed that lists the name of the printer, the font emulation, the number of fonts, the amount of memory the printer has, and the amount of pages it has printed. The last piece of information is useful in monitoring printers.

By using a printer utility program, it was possible to set up the printer so it printed this status page every time it was turned on. This produces a good indication of the daily usage of the printer. Unlike the method we used for monitoring the copier activity, we were unable to note the time each page was printed, and thus compare it to the hourly power usage of the printer.

D. Electrical Monitoring

Electrical monitoring will, in this report, refer to measurements of either true electrical power or, more simply, electrical current. True power is of vital interest when directly measuring savings due to energy management strategies. A power measurement requires that both current and voltage be measured. Current transducers can be attached around wires without having to separate electrical connections but voltage taps require that contact be made with exposed electrical connections within a machine or a modified power cord connected to the machine. Power measurements are more expensive than current measurements alone because the meter is more complicated and more difficult to make due to installation of the voltage taps. Current alone is adequate to determine when a machine is drawing power and is therefore satisfactory as a tool for measuring operating cycles. We will uniformly refer to electrical power measurements for simplicity but note that in every case a simpler current measurement can be substituted.

As noted, electrical monitoring of desktop computers provides very little information about operating profiles, because computer power is nearly constant. Importantly, monitoring indicates very clearly when computers are turned on, and the most effective and cheapest power management strategy is to turn off machines over night and weekends when they are not in use.

For imaging equipment, electrical monitoring is more fruitful, at least in principle. Typically, there are distinct differences between the electrical power required when the machine is printing an image (or as is the case with faxes, transmitting as well) or in a standby mode. As with computers, times when the machine is turned off are also easily detected, because the electrical power will be lower than for any other state and may be zero.

A low-power energy saver or suspend mode will also reveal itself as a decrease in power from the standby mode. Finally, the increase in power required by some machines when warming up after having been turned on can also be seen. In short, different operating modes are associated with different *average* powers, measured over some period of time when the machine is in a single mode.

In practice, the disaggregation of modes of operation is not so precise as to permit an exact determination of operating profile, as measured by printed, transmitted or received images. Consider, for example, copiers and printers that use a combination of heat and pressure to fuse toner to paper. The fixer drum is kept at a thermostatted temperature with a heater. The heater electrical pulses are large and occur when the machine is making images as well as when it is in the standby and energy-saver or suspend modes. The interval between pulses will shorten when the machine is printing a series of pages in succession. It is clear that there is not a one-to-one correspondence between heater pulses and printed images and that monitoring the power of the entire machine is not a simple method to determine operating profiles.

For copiers this is not a problem because it is straightforward to monitor light pulses. Faxes often produce a written printout of received and transmitted pages. For printers, using the printed log of number of pages works well. It would also be possible to measure sharp changes in electrical power drawn by the motors used to feed the paper, to avoid the problems associated with monitoring power of the entire machine, but the current transducer would need to be imbedded within the machine, making installation difficult. A magnetic transducer to sense the operation of a motor used to feed paper would also need to be placed within the printer. Looking at a printed log sheet for daily usage is far easier. For faxes, it would be difficult to imbed an optical sensor within the machine to detect the scanning that precedes image transmission. This technique would not detect received images.

Table 5.2. Example of Data for Copier A.

Time of Day	week ave. Wh/15 min.	weekend ave. Wh/15 min.	Day of week	Wh/15 min.	Day of week	Wh/15 min.	Day of week	Wh/15 min.
11:04	94	8.5	THU	83	FRI	78	SAT	10
11:19	99.6	8	THU	128	FRI	71	SAT	8
11:34	107.2	13	THU	73	FRI	88	SAT	18
11:49	119.2	69.5	THU	122	FRI	64	SAT	131
12:04	83.4	37	THU	102	FRI	68	SAT	67
12:19	92	9	THU	133	FRI	75	SAT	10
12:34	107	7	THU	108	FRI	71	SAT	6
12:49	75.4	7	THU	71	FRI	63	SAT	7
13:04	82.4	8	THU	73	FRI	64	SAT	8
13:19	62	7.5	THU	61	FRI	78	SAT	7
13:34	80.8	7.5	THU	63	FRI	89	SAT	7
13:49	86.6	7	THU	60	FRI	80	SAT	7
14:04	87.2	7	THU	112	FRI	69	SAT	7
21:04	47.8	7.5	THU	63	FRI	157	SAT	7
21:19	62.6	8	THU	65	FRI	179	SAT	8
21:34	63.8	8	THU	63	FRI	140	SAT	8
21:49	56.8	6.5	THU	66	FRI	135	SAT	6
22:04	53.4	8	THU	58	FRI	134	SAT	8
22:19	46.4	8	THU	19	FRI	133	SAT	8
22:34	45.8	7	THU	19	FRI	132	SAT	7
22:49	45.6	8	THU	18	FRI	133	SAT	8

There is an alternative to high-speed detection of electrical pulses and an attempt to associate these pulses uniquely with single images. The ASTM procedure for copiers, (see Chapter 4, section II), is based on *average* power measurements over hour-long periods in each mode. In practice, it is not possible to mandate that a machine stay in a single mode for an hour. But average power measurements at an interval shorter than an hour but longer than a second, where heater pulses are difficult to sort out, can be very fruitful. In the course of comparing measured energy consumption for copiers and printers with predictions made on the basis of test procedures, we recorded average power at 15-minute intervals and found it possible to separate the modes of operation, as follows:

1. Take one-hour measurements in each mode, as required by the ASTM test procedure for copiers, printers or fax machines. These measurements identify average power in each mode.

2. Using the hour-long measurements as a guide, assign each 15-minute interval of measured electrical power to one mode. Uncertainties due to switching modes in the middle of an interval can be reduced by taking data at shorter intervals or by interpolation. Any 15-minute interval with average power higher than the measured average power for standby mode is assumed to have included some use of the copier or printer.

Intervals where no images are printed are those where power could be reduced. These intervals are equivalent to the periods of time during which there is no keyboard activity for a computer. Table 5.2 gives a specific example from Copier A, examined in more detail below.

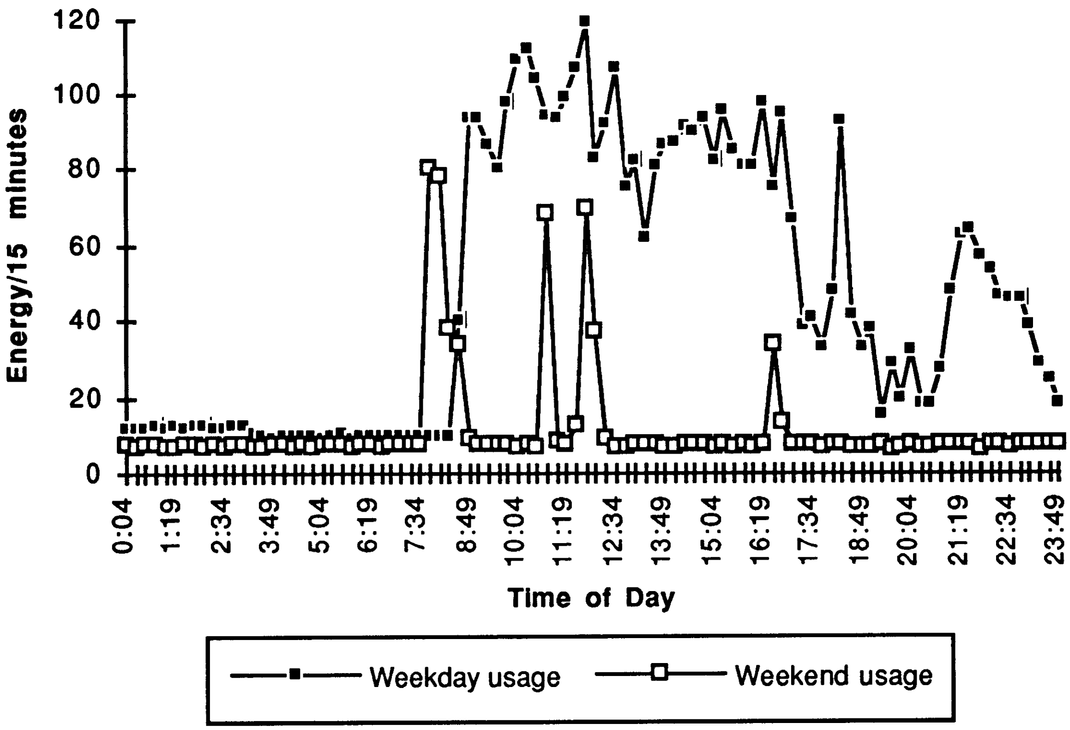

Figure 5.1. Average Energy use for Copier A.

Using the ASTM measured energy values for the different modes of this copier, we can determine the operating profiles of the machine, but only up to a certain point. For instance, on Friday at 14:04, the energy use per 15 minutes was 69 Wh/15 minutes. Standby energy for this machine is 67 Wh/15 minutes. It is unclear whether the machine was warming up the fuser, which caused a slight increase in energy, or whether one or two copies were made during that time period. A general usage pattern can be determined, as Figure 5.1 shows, giving a graphical image of the amount of energy the above copier used as a function of the time of day.

It is easy to see that usage dropped off between 12:00 noon and 2:00 PM. This fits with the activity in this particular office; the employees had a two hour lunch break between 12:00 and 2:00. Also, usage dropped off between 4:30 and 5:00, which was when the copier was generally shut off.

Examining the average energy use of a machine is not always the best way to assess the data. Following are two figures, one that gives the weekday average of energy use for copier B, and one that gives the energy use for a particular day for the same copier.

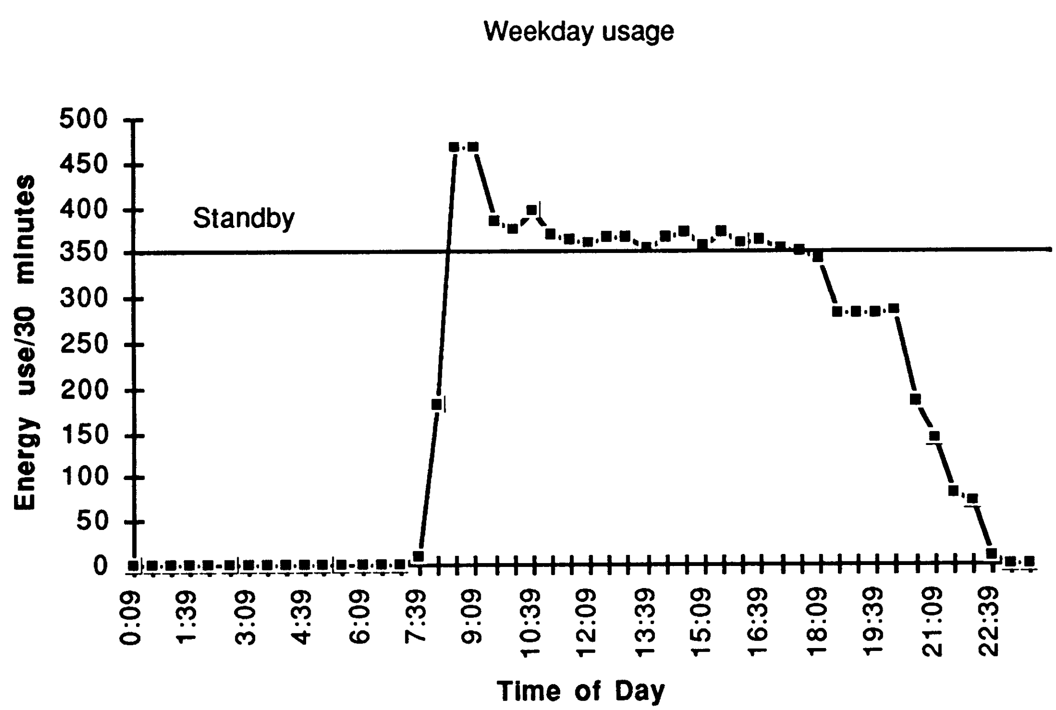

Figure 5.2. Average Energy Use for Copier B.

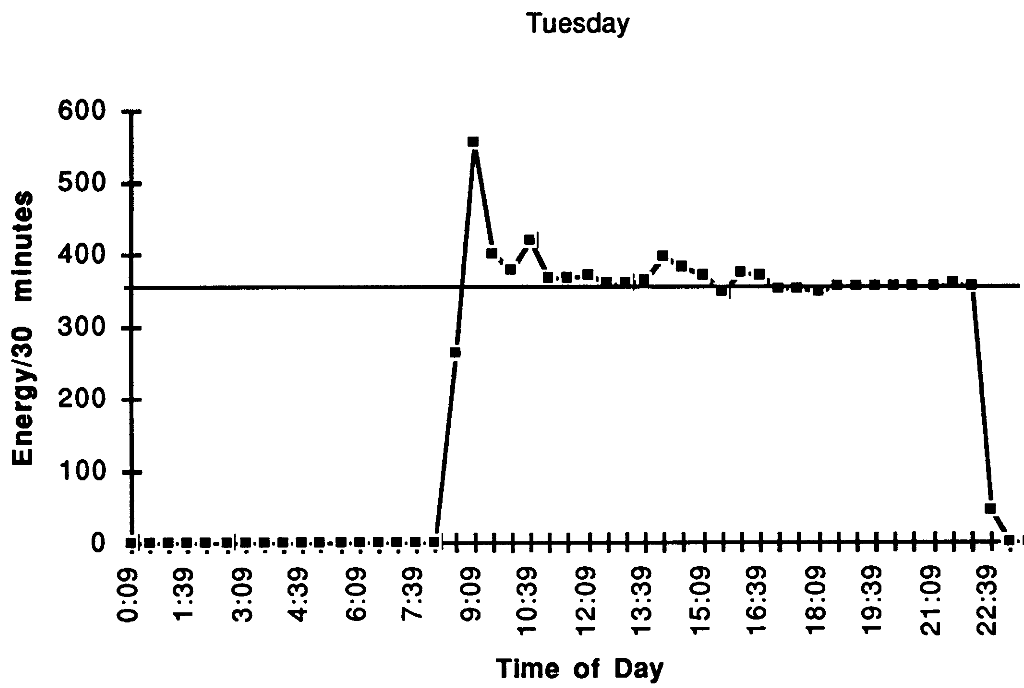

Figure 5.3. Energy Usage for Copier B Over One Day.

As can be seen, graphing the average values does not show the particular peaks during the day. While average data may give us a better idea of the total energy consumption for a particular copier, examining data from a particular day gives a slightly better graphical image of the usage. By using the individual data points, we can determine usage profiles. Therefore, when analyzing the data from various machines, data from a particular day will be examined.

III. Evaluation of ASTM Procedures for Estimating Energy Use of Copiers and Printers.

A. Comparison of Measured and Estimated Energy Consumption for Copier A.

The first copier was a large xerographic copier that fixed toner to paper with a combination of heat and pressure. It was the only copier in a university office of 50-100 people. The door to the copier was locked at 5:00, but the key was accessible. It was turned on again in the morning at about 7:00 or 8:00.

This copier was evaluated with the modified ASTM procedure on the basis of 35500 copies per month. The machine included an automatic document handler and was capable of duplexing, normal features given its size. We measured the copying energy in each of four combinations of these two features: single-sided or simplex copying with manual feed; simplex with automatic feed; duplex with manual feed and duplex with automatic feed. Hour-long measurements yielded energy consumption data shown in Table 5.3.

Table 5.3. Estimated Energy Consumption Data for Copier A, Using the ASTM Procedure[1].

	Simplex (Wh)	Simplex ADH[2] (Wh)	Duplex[3] (Wh)	Duplex ADH (Wh)
plug-in	28	28	28	28
warm-up + standby	352	352	352	352
standby	269	269	269	269
energy-saver (60 min. delay time)	243	243	243	243
copying + standby (200 copies in 1 hour)	360	345	363	359
warm-up energy	83	83	83	83
copying energy (4 min. total copying time)	91	76	94	90
copying energy/copy	0.45	0.38	0.47	0.45
plug-in energy/month (489 hours)	14532	14532	14532	14532
warm-up + standby energy/month	7040	7040	7040	7040
standby energy/month	48689	48689	48689	48689
energy-saver energy/month (30 hours per month)	7290	7290	7290	7290
copying energy/month (35500 copies)	15975	13490	16685	15975
total energy/month	93526	91041	94236	93526
average energy/copy	2.63	2.56	2.65	2.63
fraction plug-in energy	0.16	0.16	0.15	0.16
fraction idle energy (54 min. idle time)	0.60	0.61	0.59	0.60
fraction copying energy	0.17	0.15	0.18	0.17

Notes:

[1]All data in this table is obtained by using the ASTM procedure.

[2]ADH stands for Automatic Document Handler, which feeds papers to be copied automatically through the machine.

[3]Each side of a duplexed page is counted as one copy.

The data in Table 5.3 are noteworthy, even prior to comparison with the measured energy consumed by the copier. First, the four different methods of making copies make a noticeable difference in *copying* energy per copy and, of course, a smaller fractional difference in the *total* energy and average energy per copy. The automatic document handler reduces copying energy because the copies are made more quickly and there is less heat loss from the fixer drum. Duplexing requires slightly more energy than simplexed copying, due to the extra mechanical work. The relatively low copying energy for single-sided copying with the document handler should not be considered a definitive statement about the benefits of this mode, as will be shown in a second test.

Also noteworthy is the ASTM value for the energy-saver mode (see Table 4.3). This value was arrived at by pressing a button on the machine that put the copier into an energy-saver mode. However, when examining particular usage data for this machine, we noticed that after a long period when the copier was on but not in use, the energy-saver mode used 19 Wh/15 minutes, or 76 Wh. We can conclude that there may be two different energy-saver modes for this copier, something which the ASTM procedure does not account for.

For all four modes of copying, the fraction of the total energy that is ascribed to copying is a small portion of the total: 0.15-0.18. The energy consumed when the machine is plugged in but turned off is nearly equal to the copying energy in general and slightly exceeds the energy required to make single-sided copies with the automatic document handler. For all methods of making copies, the energy consumed and dissipated as heat when the copier is idle is about two-thirds of the total. The energy saver button reduced the average power required in standby mode from 269 Wh/h to 243 Wh/h, only 10%. However, the deeper sleep the copier seemed to go into reduced the average power from 269 to 76, a reduction of about 71%. For the copy volume considered in this test, over 80% of the total energy (as estimated by the ASTM procedure) is used non productively, when the machine is turned off or idle.

Table 5.4. Estimated Energy Consumption Data for Copier A--Higher Copying Volume[1].

	Simplex (Wh)	Simplex ADH (Wh)	Duplex (Wh)	Duplex ADH (Wh)
plug-in	28	28	28	28
warm-up + standby	352	352	352	352
standby	269	269	269	269
energy-saver	243	243	243	243
copying + standby (256 copies in 1 hour)	375	373	368	362
warm-up energy	83	83	83	83
copying energy	106	104	99	93
copying energy/copy	0.41	0.41	0.39	0.36
plug-in energy/month (489 hours)	13690	13690	13690	13690
warm-up + standby energy/month	7040	7040	7040	7040
standby energy/month	48689	48689	48689	48689
energy-saver energy/month	7290	7290	7290	7290
copying energy/month (45223 copies)	18740	18740	17640	16280
total energy/month	95436	95083	94200	93140
average energy/copy	2.11	2.10	2.08	2.06
fraction plug-in energy	0.14	0.14	0.15	0.15
fraction idle energy	0.59	0.59	0.60	0.60
fraction copying energy	0.20	0.20	0.19	0.17

Notes:

[1]All data in this table is obtained by using the ASTM procedure.

The actual energy use and copy count (not that calculated by the ASTM procedure) were measured for this copier over a 7 day period and scaled up to a 30-day month, for which the machine would have made 45223 copies and used 107110 Wh of electrical energy, or 2.37 Wh/copy. The ASTM initial test was performed for an estimated monthly copying volume of 35500. To permit a direct comparison with actual test data, the ASTM test procedure results can be scaled to a higher volume or, more accurately, the ASTM test can be repeated. To scale the results, a lower bound for the ASTM average energy per copy is derived by simply dividing the total energy per month as derived in the ASTM test procedure by the higher copy volume, yielding 1.95-2.02 Wh/copy. The lower bound assumes that more copies can be made with no increase in total energy. The upper bound assumes that the same copying energy per copy would apply to a larger copying volume, even though larger volumes are typically produced more efficiently; this assumption yields 2.03-2.12 Wh/copy. To check the validity of the upper and lower bounds and to determine a more precise answer, the hour-long ASTM copying test was repeated for a higher copying volume, as shown in Table 5.4.

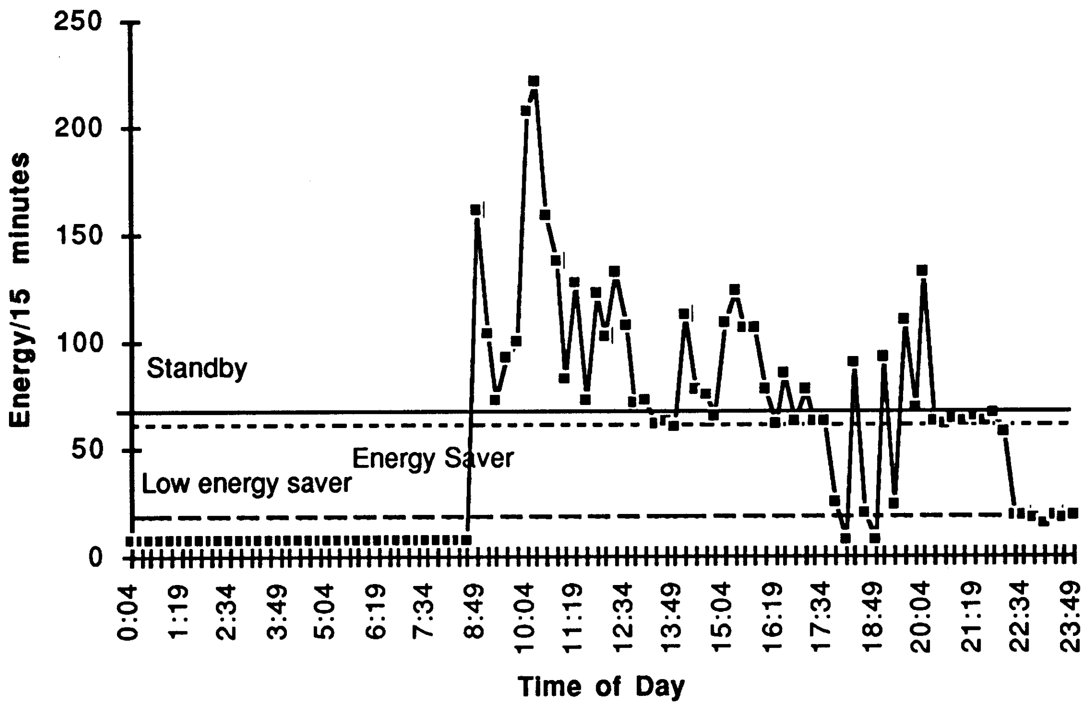

Figure 5.4. Energy Use for Copier A , Over One Day.

The second test shows that according to the ASTM test procedure, the document handler reduced copying energy for both simplexed and duplexed copying by a very modest amount: 2-6 Wh for 256 copies. Interestingly, duplexed copying was measured with the ASTM procedure to use slightly less energy than simplexed copying, a counter-intuitive result that may be due to the copier's being slightly warmed for the duplexed tests. The total energy per month varied from 93140 to 95436 Watt-hours, compared with the measured value of 107110 Wh. The average energy/copy for the four tests ranged from 2.06 to 2.11 Wh/page, compared with a measured value of 2.37 Wh. The ASTM test results fall between the upper and lower bounds, as anticipated, and underestimate measured values by 11-13%.

The comparison between measurement and prediction can be extended to the energy required when the machine is idle or turned off as well as when it is making copies. Using the 15-minute average actual energy data and disaggregation methodology using the ASTM procedure described above, we first separated and classified the data by operating modes and summed the time the machine spent in each mode. We then assigned to each mode the separately measured average power (from the ASTM procedure), a more streamlined approach than adding the energy from each 15-minute segment, and calculated the disaggregated energy use shown in Table 5.5. A graphical representation of the average amount of energy the copier used in 15 minute intervals, as compared to the time of day can be seen in Figure 5.1. Of note is the standby energy usage, and the two energy saver modes noted above.

Table 5.5. Disaggregation of Copier Energy Use and Comparison with Estimate for Copier A[1].

	Disaggregation of Actual Measured Energy	Estimate from ASTM Test Procedure
plug-in hours/month	418	489
warm-up + standby hours/month	56	20
standby + copying hours/month	166	181
energy-saver hours/month	80	30
plug-in energy/month (Wh)	11700	13690
warm-up + standby energy/month (Wh)	19710	7040
standby energy/month (Wh)	44650	48689
energy-saver energy/month (Wh)	19440	7290
standby + energy-saver energy/month (Wh)	64090	55979

Notes:

Both actual and ASTM values are given here.

Plug-in energy as disaggregated from actual measured energy consumption is lower than estimated from the ASTM test procedure, because the copier was powered for 71 more hours per month than assumed by the ASTM procedure. The copier was also turned on 36 more times than assumed by the ASTM procedure, due to users working at night and over weekends.

The actual measured data show less energy in standby mode than estimated by the ASTM procedure, and more in the energy-saver mode, and more in the sum of the two. This reflects the fact that the machine spent 15 fewer hours in standby and 50 more hours in energy-saver mode than assumed by the test procedure. The difference in hours can be accounted for by the fact that the machine was on more hours than predicted. The total actual energy spent for all activities *except* copying, 95510 Wh, exceeded the prediction by the ASTM procedure of 76710 Wh by 18800 Wh. For simplexed copying with the document handler, the actual measured monthly total energy of 107110 Wh exceeded the estimated total by the ASTM procedure of 95083 Wh by 12,027 Wh, less than the difference when copying is excluded. This indicates that the difference in total monthly energy between actual measured energy use and the predicted use by the ASTM procedure is due mainly to longer hours of operation and more warm-up cycles. It also points to the limited accuracy of the energy disaggregation procedure that we used, because it leads to the conclusion that the copier used less than the predicted amount of copying energy to make more copies, to the extent that the disaggregation suggests that copying energy was 0.26 Wh/copy, compared with one-hour ASTM measurements of 0.36-0.41 Wh per copy.

It should be noted that the test procedure assumes that copying takes place during the time allocated to standby. The energy data alone are not sufficient to pinpoint those 15-minute intervals in which copies were made, because there is some scatter in the data and intervals with a small number of copies cannot be distinguished from those with none. When examining standby energy, however, we need not include the copying energy because the ASTM procedure does not allot time to copying, since the ASTM measured copying energy necessarily includes standby energy as well. The ASTM procedure measures the copying energy with the standby energy, then subtracts the standby using this number for the calculations.

B. Comparison of Measured and Estimated Energy Consumption for Copier B

The comparison between actual measurements and ASTM predicted energy consumption was repeated for a second high-volume copier that uses heat and pressure to fix the toner to paper. The copier was in an administrative office of 10-20 people. The office was locked at 5:00, and reopened at 7:00 or 8:00.

This machine featured a different type of energy saver mode: it turned off after two hours of inactivity. As with copier A, the ASTM test procedure was initially run for a copying volume that differed from actual and was subsequently adjusted. Table 5.6 shows the results of applying the modified copier energy-consumption test procedure with the initial estimate of 25000 copies per month.

Table 5.6 indicates that this copier uses no power when it is plugged in but turned off, an improvement compared to copier A. But standby energy use is high and the duplexer is less energy-efficient than the duplexer in copier A. For simplex copying, only 0.12 of the total energy is used productively.

Table 5.6. Estimated Energy Consumption Data for Copier B[1].

	Simplex (Wh)	Simplex ADH (Wh)	Duplex ADH (Wh)	Lumped Simplex (Wh)	Spread Simplex (Wh)
plug-in	0	0	0	0	0
warm-up + standby	1146	1146	1146	1146	1146
standby	703	703	703	703	703
energy-saver	703	703	703	703	703
copying + standby (144 copies in 1 hour)	831	829	982	811	890
warm-up energy	443	443	443	443	443
copying energy	128	126	279	108	187
copying energy/copy	0.89	0.62	1.38	0.53	0.93
plug-in energy/month (489 hours)	0	0	0	0	0
warm-up + standby energy/month	25212	25212	25212	25212	25212
standby energy/month	101232	101232	101232	101232	101232
energy-saver energy/month	22496	22496	22496	22496	22496
copying energy/month (25000 copies)	22220	21875	48440	18750	32465
total energy/month	171160	170815	197380	167690	181405
average energy/copy	6.85	6.83	7.90	6.71	7.26
fraction plug-in energy	0.00	0.00	0.00	0.00	0.00
fraction idle energy	0.72	0.72	0.63	0.74	0.68
fraction copying energy	0.13	0.13	0.25	0.11	0.18

Notes:

[1]All data in this table is obtained by using the ASTM procedure.

Table 5.6 also shows the variation in copying energy due to timing between individual copies. The test requires that 144 copies be made in an hour. For simplex copying, these were spaced according to the test procedure. We also made the same number of copies first by lumping them in as short a time as possible and by spreading them uniformly over the hour. Less energy is required to make copies when there is little time between them. Lumped copying reduces the copying energy per page from 0.63 Wh to 0.53 while spreading the copies increases energy use of 0.93 Wh per page. The average energy per copy (including idle energy) drops from 6.85 Wh/copy to 6.71 Wh/copy for lumped copying and rises to 7.26 Wh/copy when the copies are spread.

Based on a week of actual measured data, this copier would produce 11090 copies per month rather than the ASTM predicted 25000 copies, and consume 198690 Wh per month or 17.9 Wh/copy, compared to the predicted 6.7-7.9 Wh/copy. The ASTM measured data were disaggregated as for copier A. The comparison for copier B, as shown in Table 5.7, indicates that the actual measured value for warm-up plus standby energy was 2% less than the ASTM predicted value and the predicted for standby energy was 25% more than measurement, because the copier in fact spent more time in standby, and a little less in a warm-up mode than the test procedure estimates. The agreement is reasonably good for the warm-up mode, suggesting that the major difference between the measured and predicted values for average energy per copy is both that the copier was on for a longer period of time, and it made fewer than the estimated number of copies.

Table 5.7. Disaggregation of Copier Energy Use and Comparison with Estimate for Copier B[1].

	Disaggregation of Measured Energy	Estimate from ASTM Test Procedure
plug-in hours/month	467	519
warm-up + standby hours/month	21	22
standby + copying hours/month	232	176
warm-up + standby energy/month (Wh)	24560	25210
standby energy/month (Wh) (no energy saver)	163110	123730

Notes:

[1]All data in this table is obtained by using both actual usage data and the ASTM procedure.

As can be clearly seen from Figure 5.3 (also included in section 2), it is difficult to determine the difference between standby and copying modes. A small dip can be seen around the lunch time hour, and peak around 8:00 due to the increase in power from when the copier is first turned on.

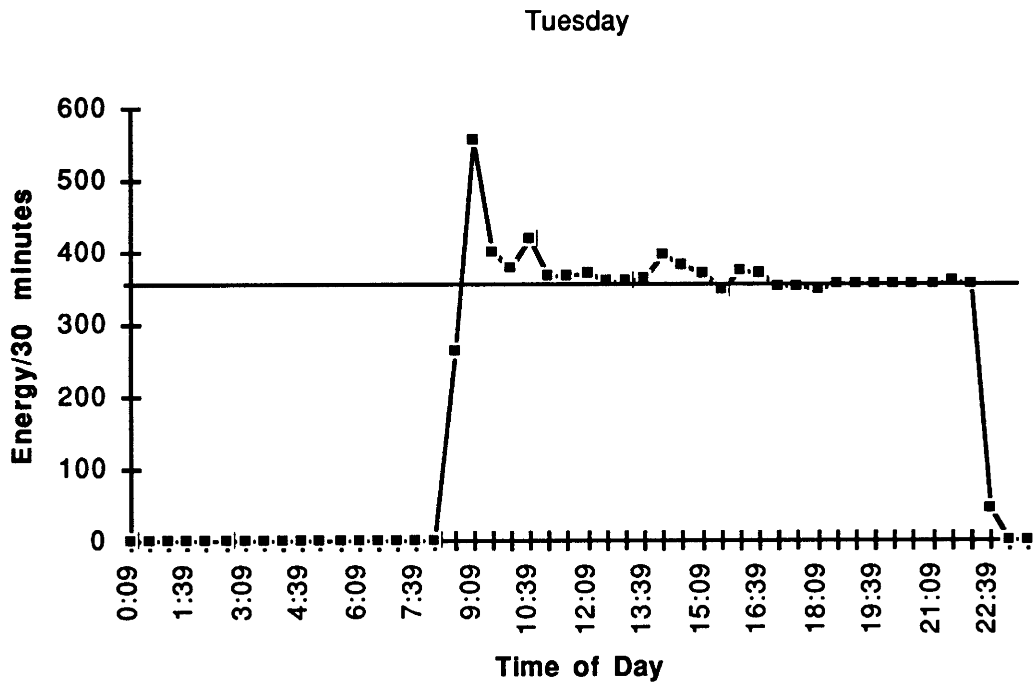

Figure 5.3. Energy Usage for Copier B Over One Day.

The impact of the difference in copying volume can be bounded without repeating the hour-long test of energy consumption while making a smaller number of copies that corresponds to the measured copying volume. The copying energy per copy as predicted from the test procedure can be divided by 63 copies rather than 144, and then multiplied by 11090 rather than 25000, yielding a new ASTM predicted average energy per copy of 15.5-17.9 Wh, depending on the method of making copies (simplex with ADH at the low end, duplex with ADH at the high end). A lower bound comes from using the same amount of copies, 144 under which the test was performed, which takes no account of the variation in copying energy per copy with copying volume. This calculation yields 14.3-15.4 Wh/page. The first figure contains the measured value of 17.9 Wh/page. However, since the machine was in fact idle for longer than predicted by the ASTM procedure, we can assume that this would account for most of the difference.

The hour-long ASTM measurement of copying energy was repeated as a check, for simplex copying with and without the automatic document handler. The key results, contrasted with those obtained for the higher copying volume, are shown in Table 5.8. The low-volume ASTM data for single-sided copying with manual feed are abnormally low: Copying energy per copy was about 63% that required when the document handler was used, rather than a slightly higher value, as expected on the basis of other tests. There are inaccuracies associated with taking the difference of two large numbers--energy required for standby alone and that used during an hour of standby and copying activity--to derive a smaller number--copying energy. The average energy per copy for simplex copying with the document handler is very close to the upper bound established from the first test. That is, there was very little decrease in total energy as the copying volume decreased.

Table 5.8. Comparison of Copying Energy, as Determined by Test Procedure, for Low and High Copying Volumes[1].

	Simplex high volume	Simplex low volume	Simplex ADH high volume	Simplex ADH low volume
copies/hour	144	60	144	60
copies/month	25000	11090	25000	11090
standby energy (Wh)	703	703	703	703
copying + standby energy (Wh)	831	778	829	822
copying energy	128	75	126	119
copying energy/copy	0.89	1.19	0.88	2.00
copying energy/month	22222	13202	21875	22180
total energy/month	171162	162142	170815	171120
average energy/copy	6.9	14.7	6.8	15.4
fraction plug-in energy	0.00	0.00	0.00	0.00
fraction idle energy	0.72	0.76	0.72	0.74
fraction copying energy	0.13	0.08	0.13	0.11

Notes:

[1]All data in this table is obtained by using the ASTM procedure.

As can be seen from Figure 5.3, usage is fairly constant over the day. The peak in the morning is due to the warm-up energy when the copier is first turned on. From Figure 5.2 we can see that this happened at roughly the same time every day. Figure 5.3 shows peaks before and after lunch time. Figure 5.2 shows that turn-off time at night happens at varying times. Of note is the fact since the copier had an auto shut-off, there is no nighttime or weekend usage at all.

C. Comparison of Measured and Estimated Energy Consumption for Copier C.

Copier C is a light-duty table-top machine in use in a small office of 20-30 people. Access to the copier was available at all times of the day. Primarily, the copier was shut off at 7:00 PM and turned on in the morning at 6:00 or 7:00 am.

Table 5.9. Estimated Energy Consumption Data for Copier C[1].

	Simplex 2500 copies/month (Wh)	Simplex 4272 copies/month (Wh)
plug-in	0.07	0.07
warm-up + standby	594.7	594.7
standby	580.6	580.6
energy-saver	580.6	580.6
copying + standby (14 copies in 1 hour-low, 24 copies in 1 hour-high)	608.6	652.7
warm-up energy	14.1	14.1
copying energy	28	72.1
copying energy/copy	2.00	3.00
plug-in energy/month (489 hours)	34	34
warm-up + standby energy/month	11890	11890
standby energy/month	105090	105090
energy-saver energy/month	17418	17418
copying energy/month	5000	12830
total energy/month	139430	147720
average energy/copy	55.8	34.6
fraction plug-in energy	0.00	0.00
fraction idle energy	0.88	0.83
fraction copying energy	0.03	0.09

Notes:

[1]All data in this table is obtained by using both actual usage data and the ASTM procedure.

The ASTM test data, as presented in Table 5.9, shows that this copier requires an average of 55.8 Wh/copy to make each of 2500 copies per month. According to the procedure, only three percent of the energy is used productively. The test was repeated for a copy rate to match the measured copy volume of 4272 copies per month and the average energy per copy dropped to 34.6 Wh/copy, with nine percent of the total energy used productively.

Measurements were made of the copier's energy. Because the copier lacked a counter, we used the optical sensor to record the number of copies. For copy volume of 4272 copies per month, the average energy per copy according to the ASTM procedure was measured to be 36.8 Wh/copy. Using the measured usage patterns for the copier, the average energy per copy was estimated to be 41.4 Wh/copy. For the same copying volume, the ASTM predicted energy use was six percent lower than the measured value. The ASTM data have not been disaggregated to pinpoint the cause of the discrepancy.

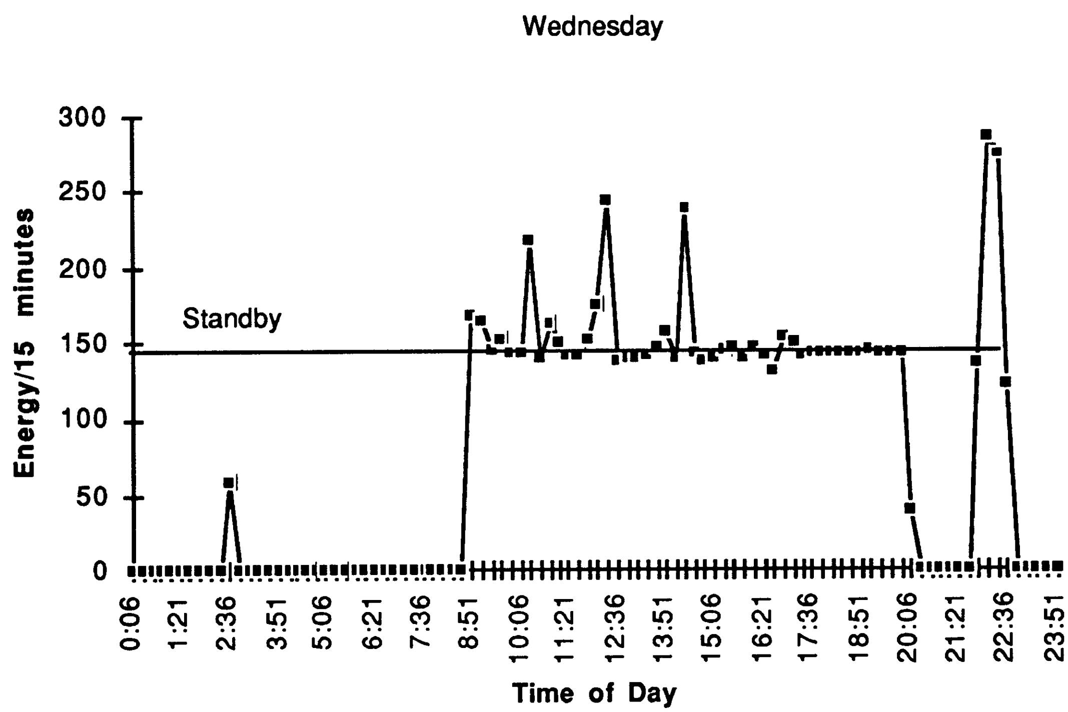

Figure 5.5. Energy usage for Copier C, Over One Day.

The test data for the lower copying volume can be adjusted as for copier B, without repeating the test. The upper bound is 33.4 Wh average energy per copy, derived from adding to the total ASTM predicted energy shown in Table 5.7 an amount corresponding to making an additional 1772 copies at 2.00 Wh/page copying energy. The lower bound is 32.6 Wh/copy, derived by simply dividing the total ASTM predicted energy shown in Table 5.7 by the measured number of copies. The upper bound is closer to the mark and in fact slightly underestimates the results of the second test.

Usage patterns are clear from Figure 5.5. The copier was not used around lunch time, or at the end of the day. It was turned on and off three times during the day, instead of the assumed one time. The line for the standby energy clearly shows that for most of the day, the copier was in a standby mode.

D. Comparison of Measured and Estimated Energy Consumption for Four Printers.

Table 5.10. Estimated Energy Consumption for Printer A[1].

	Simplex 5000 copies per month (Wh)	Simplex 10000 copies per month (Wh)	Simplex 25000 copies per month (Wh)
plug-in	0.2	0.2	0.2
warm-up + standby	91.4	91.4	91.4
standby	77.2	77.2	77.2
energy-saver	77.2	77.2	77.2
printing + standby	87.5	94.7	109.4
warm-up energy	14.2	14.2	14.2
printing energy	10.3	17.5	32.2
printing energy/page	0.37	0.32	0.21
plug-in energy/month (489 hours)	97.8	97.8	97.8
warm-up + standby energy/month	1828	1828	1828
standby energy/month	13973	13973	13973
energy-saver energy/month	2316	2316	2316
printing energy/month	1840	3240	5590
total energy/month	20050	21460	23805
average energy/page	4.01	2.15	0.95
fraction plug-in energy	0.00	0.00	0.00
fraction idle energy	0.81	0.76	0.68
fraction printing energy	0.09	0.15	0.23

Notes:

[1]All data in this table is obtained by using both actual usage data and the ASTM procedure.

The proposed ASTM test procedure for printers was applied to four machines but measured energy consumption data were only taken for the last three. The first was a 10 page/minute LED printer with an amorphous silicon drum. It lacked an energy saver mode. Total energy is again dominated by what is consumed when the machine is idle and is not sensitive to the printing volume, as shown in Table 5.10. ASTM Energy per printed page drops by over a factor of 4 as monthly printing volume increases by a factor of 5.

The test was repeated for a laser printer that was networked between roughly 40 computers, but was not the only printer on the network. The energy consumption and printing volume were both measured over a six-day period. The test procedure results are shown in Table 5.11.

Table 5.11. Estimated Energy Consumption Data for Printer B[1].

	Simplex 352 copies per month (Wh)
plug-in	0.0
warm-up + standby	109.0
standby	104.0
energy-saver	104.0
printing + standby	111.6
warm-up energy	4.9
printing energy	7.6
printing energy/page	3.8
plug-in energy/month (489 hours)	0.0
warm-up + standby energy/month	2180
standby energy/month	18820
energy-saver energy/month	3120
printing energy/month	1338
total energy/month	25460
average energy/page	72.33
fraction plug-in energy	0.00
fraction idle energy	0.86
fraction printing energy	0.05

Notes:
[1]All data in this table is obtained by using both actual usage data and the ASTM procedure.

Printer C is an 8 page per minute printer, networked between 6 users. Primarily, it is turned on at 7:00 in the morning, and switched off between 7:00 and 8:00 at night. Figure 5.6 compares the energy consumed by the printer every 15 minutes to the time of day.

Table 5.12. Estimated Energy Consumption Data for Laser Printer C[1].

	Simplex Usage A
plug-in	.35
warm-up + standby	81
standby	78
energy-saver	78
printing + standby (144 copies in 1 hour)	83
warm-up energy	3.02
printing energy	5.1
printing energy/copy	1.02
plug-in energy/month (489 hours)	171
warm-up + standby energy/month	1620
standby energy/month	16460
energy-saver energy/month	0
printing energy/month (25000 copies)	918
total energy/month	19168
average energy/page	21.3
fraction plug-in energy	0.01
fraction idle energy	0.86
fraction printing energy	0.05

Notes:

[1]All data in this table is obtained by using both actual usage data and the ASTM procedure.

The printer showed very different usage cycles than those assumed by the ASTM procedures. Figure 5.6 graphically depicts the usage pattern over a one week period. As can be seen from the figure, there is no great distinction between the energy the machine uses when printing and when in standby.

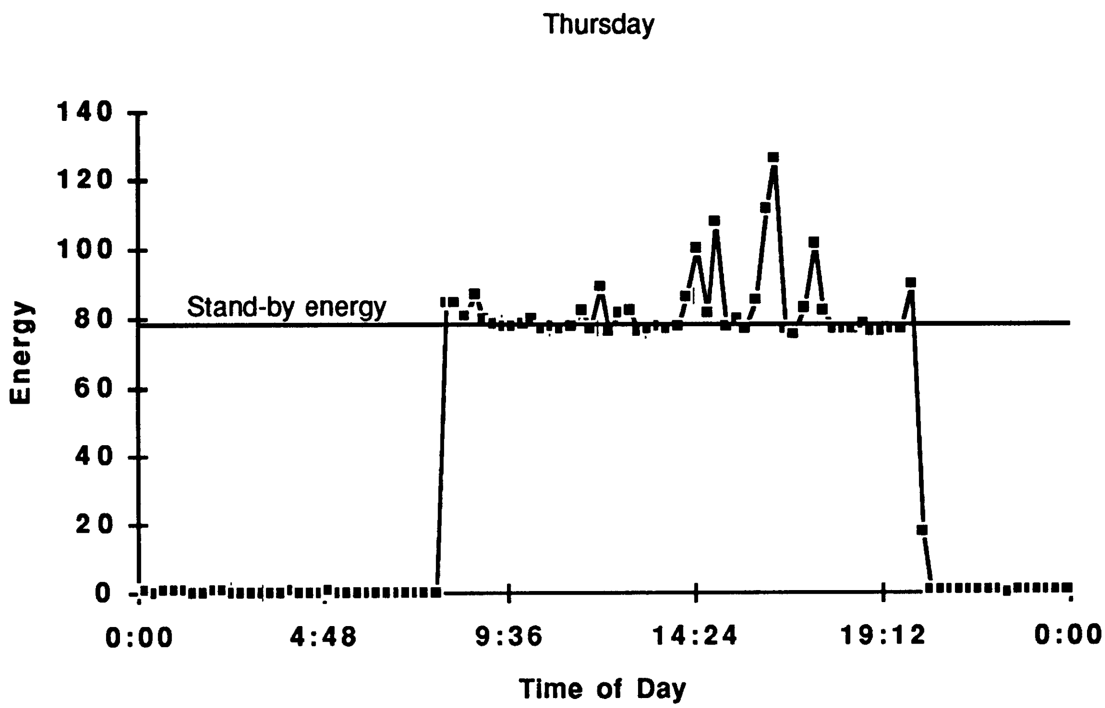

Figure 5.6. Energy usage for Printer C, Over One Day.

It is clear from Figure 5.6 that the machine was in stand-by for a large percentage of the time; it was in a stand-by mode 211 hours more than was assumed by the ASTM procedure. It was also on 165 hours more. The actual total energy use for one week was 30788. By using the number of hours the printer was actually in certain modes, and re-calculating the ASTM values, we arrived at a value of 30186 for a new total ASTM energy use. Predicted values using the original assumptions in the ASTM procedure gave 19168 Wh per month. The difference in idle energy accounted for most of the difference; the total difference was 12856, and the idle energy difference was 13728. When using the actual hours of use with the ASTM procedure, the predicted value for the total energy use is only 2% off the actual value.

Table 5.13. Disaggregation of Energy Use and Comparison with Estimate, Printer C[1].

	Disaggregation of Measured Energy	Estimate from ASTM Test Procedure
plug-in hours/month	324	489
warm-up + standby hours/month	9	20
standby + copying hours/month	387	211
possible energy-saver hours/month (5 min. delay)	260	34
plug-in energy/month (Wh)	113	171
warm-up + standby energy/month (Wh)	810	1620
standby energy/month (Wh) with energy-saver mode	9910	5900
possible energy-saver energy/month (Wh)	1300	680
standby energy/month (Wh) without energy-saver mode	30186	16460

Notes:

[1]All data in this table is obtained by using both actual usage data and the ASTM procedure.

It is interesting to note the possible energy savings if the printer above went into an energy saver mode after 5 minutes of non-use. Of the 308 hours the machine was actually in a stand-by mode, it could have been in an energy-saver mode 260 hours, or 84% of the time. By using a value of 5W, a value for an energy-saver mode that some machines currently have, and the numbers given by the operating profiles, we arrived at a total energy usage of 19290. If the ASTM procedure were used to predict the total energy usage, we arrived at a value of 14650, a 25% difference from what is expected using the operating profiles. One of the main causes for discrepancy is probably because for the machine we tested, even though the actual amount of pages that were printed matched the predicted values, there were extended periods of time when the machine was not in use.

Another printer, printer D, of the same model as printer C was also monitored. This printer had a very different usage pattern; it was frequently turned off when not in use. The printer was also networked between 6 different computers, which were used in an office of 15-20 people. Printer D printed almost twice as many pages in one week as printer C (408 compared to 285 for the week), but only used 60% of the amount of energy that printer C used (4346 compared to 7184 for the week). Following is a graphical representation of the average energy use of both printers C and D.

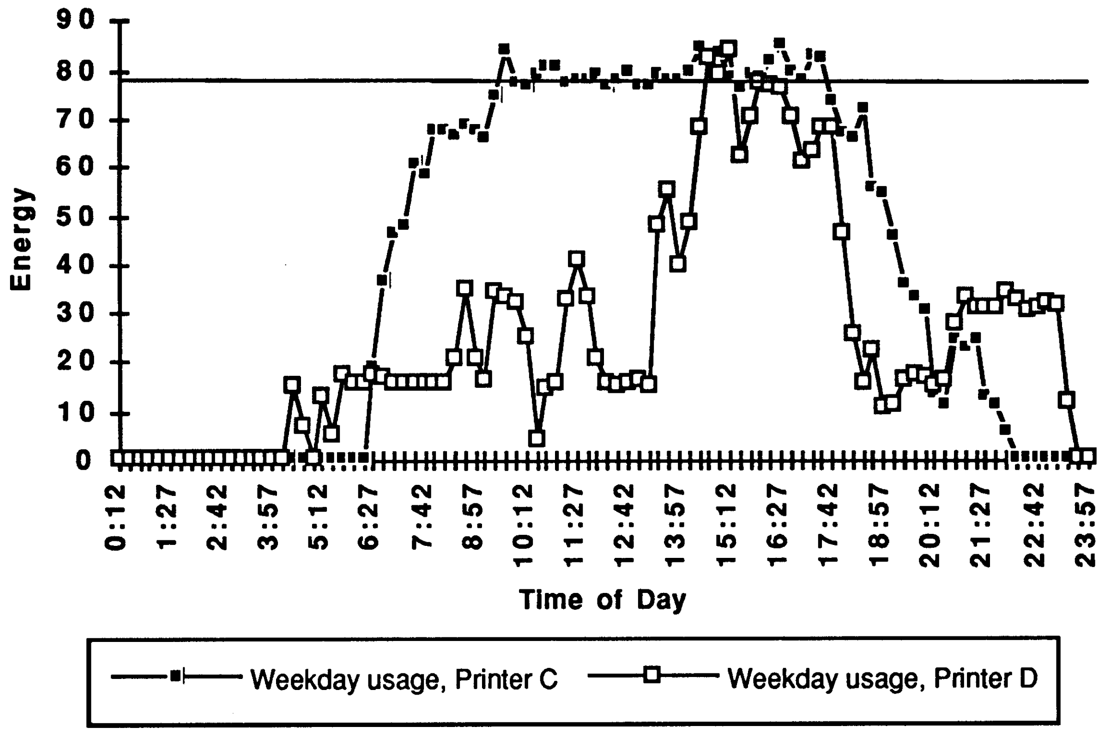

Figure 5.7. Average Energy use for Printers C and D.

In effect, printer D had an energy-saver mode; even though it was manually switched off, it was switched off when not in use. The two printers were in the same office; both groups of users were in the office at roughly the same times. Therefore it is easy to assume that if printer C had an energy-save mode, the usage pattern would be similar to that of printer D.

E. Summary of Comparisons for All Machines

Close agreement between the average energy per copy or printed page predicted by the test procedure and measured performance can be expected if the hours of use assume by the ASTM test procedure matches the actual hours of operation and the number of copied or printed images. The estimate becomes stronger if there is no energy saver mode, because it is difficult to predict the time a given machine will spend in this mode. When there is no energy-saver mode, total energy is not sensitive to the volume of output, increasing for the printer by less than 15% as printing volume increased by a factor of 5.

For machines with an energy saver, it is anticipated that the test procedure will underestimate the time spent in this mode for low copy volumes and overestimate the time under high usage. Copier A spent less time in the energy-saver mode than estimated by the test procedure.

When actual hours of operation greatly exceed the estimate, as with the laser printer, the test procedure's results bear little relation to the measured data.

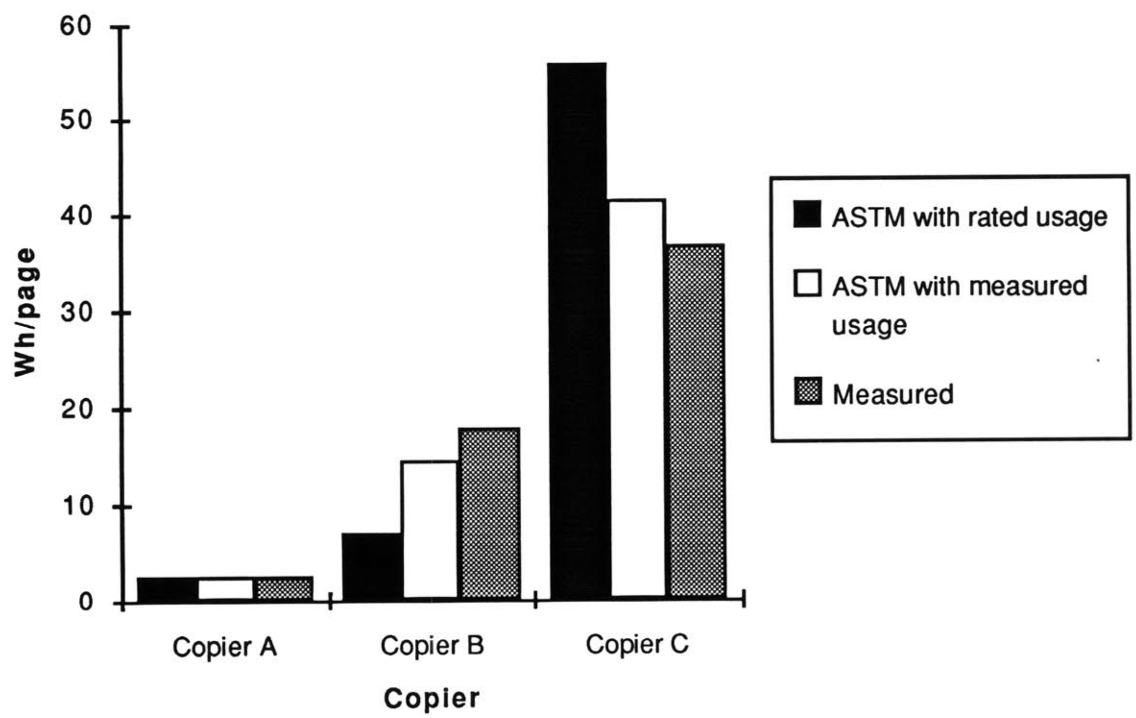

Figure 5.8. Average Energy per Page for Each Copier, Varying Methods of Measurement.

In Figures 5.8 and 5.9 , the average energy per page for each machine is graphically represented. The ASTM with rated usage values represent the average energy per page using the manufacturers rated monthly volumes for each machine, and the usage patterns assumed by the ASTM procedures. The ASTM with measured values represent the average energy per page of the machine, using the estimated number of hours the machine would be in each mode from the measured usage patterns. Finally, the measure values are the measured total energy of the machine, divided by the measured number of imaged pages per each machine. The second two values are measured for one week, and correlated to an average month, as defined by the ASTM procedures.

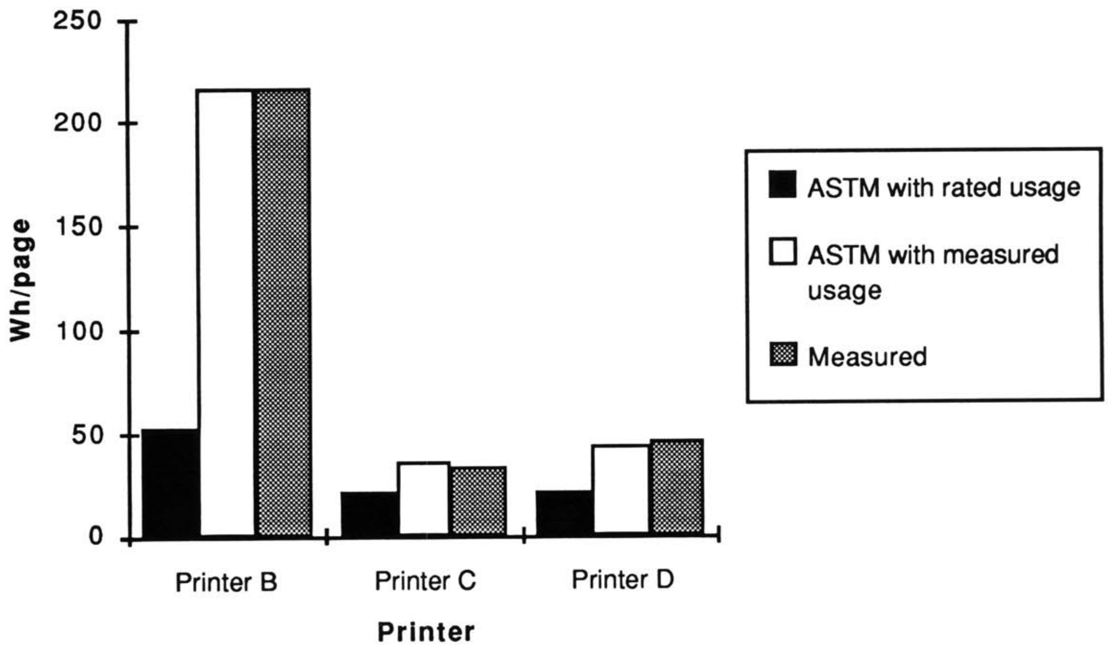

Figure 5.9. Average Energy per Page for Each Printer, Varying Methods of Measurement.

Figure 5.8 shows a strong correlation primarily between the ASTM value calculated with actual usage data and the measured value. With Copier C, usage was spread over the day, which does not match the ASTM predicted usage pattern in the job matrix, which might account for the discrepancy. Because of the spread usage patterns, it was very difficult to judge when the machine was in a standby mode, so it was hard to predict actual usage data.

The printers showed a very strong correlation between the ASTM values using measured usage data, and actual measured data. In the one case of Printer B, the ASTM value using rated usage data was much less than the measured value. Printer B was left on all the time, giving very different usage patterns than predicted ones.

Table 5.14. Energy Use per Page, Varying Methods of Measurement.

Unit	ASTM Rated Energy Use (Wh/page)	ASTM with Measured Operating Profiles (Wh/page)	Actual Measured Energy Use (Wh/page)
Copier A	2.63	2.53	2.37
Copier B	6.85	14.62	17.9
Copier C	55.77	41.41	36.8
Printer B	52	216.5	216.9
Printer C	21.30	35.74	34.36
Printer D	21.30	43.17	45.65

Using ASTM rated values can give a very good basis for comparison between like machines, but does not often give the same values that the use of actual usage patterns would give. By collecting usage data by examining energy usage over a certain interval, and predicting hours of machine usage in each mode, and applying them in the ASTM procedure, we arrived at values very close to the measured values for each machine. Table 5.14 shows that for copiers, the ASTM rated energy use per page was from 10-161% different from the actual measured energy use per page. The use of the ASTM method with the measured operating profiles of the machine gave a 7-22% difference in energy use per page. For printers, the rated values using the ASTM method gave 61-317% difference from the actual measured energy use per page, while using actual usage profiles with the ASTM method gave 0-6% difference.

Conclusion

I have presented here several tools for assessing energy-efficient office technologies today. I performed a policy assessment which can provide policy makers, researchers, and procurement agencies needed information on a variety of programs emerging in this area. The technology assessment provides an overview of personal computers, monitors, copiers, fax machines, printers, and combined devices. It was used as the technical basis for a recent buyer's guide produced by ACEEE (Ledbetter, Smith 1993). The technical assessment can be used with this buyers guide to help energy analysts and electric-utility researchers and those responsible for implementing demand-side management programs, and can also be used by procurement officers and facility managers in choosing the right office equipment. The test procedures I wrote for ASTM and COPEE should be useful to those responsible for developing testing and information programs, by providing a definitive way of testing copiers, printers, fax machines and personal computers. If used consistently, these test procedures can provide an accurate comparison for users wanting to choose office equipment. I then used these test procedures to investigate operating profiles for imaging technology and their impact on energy use of the machines. This should be useful to a variety of people, in particular energy analysts and those responsible for implementing demand-side management programs.

With the policy assessment in Chapter 2, I identified the key players in each country, and presented the kind of future work that needed to happen to implement some of the emerging programs in this area. The technical assessment provided a look at some of the trends in the energy use of computers, monitors, printers, fax machines and copiers. I presented some values for energy and power usage for various types of machines, but concentrated on the trends in various technologies. There is currently a trend for office equipment to use more power in the operating modes of the equipment, but with power management, the trend towards a higher overall energy use is being diminished. Also, new technologies that use less energy like ink jets and liquid crystal displays, are minimizing this trend.

Energy efficiency technologies in copiers are significantly lagging other the technology in office equipment. The test procedures can be used to develop a data base, which in turn can be used to look at specific copiers that use more efficient technologies, or have better power management built into them. Development of the test procedures has gone a long way. Hopefully, there will be published versions in the next few months.

I examined in part, the usefulness of these test procedures by comparing rated values given by the procedures to measurements taken with operating profiles. The test procedures can be used with actual operating profiles to determine the actual energy usage of the machine, within an accuracy of 22 %.

A. Future Studies

Since office technologies are the products of an industry where rapid and constant improvement is essential for survival, technical assessments should be made frequently. For future study, I would recommend primarily the continuation of technical and policy assessments in this area. Most importantly, some attempt to identify strategies to encourage development in this area should be made in order to speed deployment of energy-efficient technologies into the marketplace. In particular, greater focus needs to be paid to copiers and fax machines.

None of the past reports on office equipment have addressed the question of which strategies should be taken to encourage the development and manufacture of energy-efficient office equipment, and what is needed to see their deployment in a timely fashion. Two recent programs have attempted to address these issues: COPEE's voluntary testing and information program with manufacturers, and the Energy Star program. While this last program addresses energy-efficiency issues in monitors, printers and computers by providing a voluntary labeling program to help manufacturers market energy-efficient monitors, printers and computers, it does not address the testing and information issues of these products, nor is it concerned with copiers and fax machines.

In the next year, I will work under a grant from the EPA to determine whether it is appropriate to proceed with a voluntary labeling program, or whether additional measures are necessary, such as a market pull program or golden carrot approach. This type of approach would give funding to one or several manufacturers for the development of an energy efficient technology in a certain area. If a golden carrot program needs to be developed, the project will be focused to develop criteria for this type of approach. Copiers, facsimile machines and other types of equipment will be investigated.

In terms of the policy assessment, many groups have formed recently to study different aspects of energy efficiency in office equipment, in the United States and internationally. Criteria to evaluate and label energy-efficient equipment are being proposed now in many different countries, with different implications on market, cost and energy savings. An analysis should be performed of these different program criteria, addressing several issues. First, the impact of energy-efficient technologies on product performance and customer acceptance, which needs to be assessed through discussions with industry and through consideration of programs already performed. Of particular interest is the impact on productivity of the time required for equipment to move between states of different power levels. Second, industry views about the best approach to developing program criteria should be examined. Approaches favored by electric utilities to achieve energy conservation and reduction in peak loads also need to be examined. Experts should be contacted to determine the peak load reduction expected from utilization of energy-efficient copiers and fax machines. And finally, an further assessment of the ASTM procedures for testing energy consumption of copiers and fax machines needs to be performed to determine ease of use and accuracy of results of these test methods. I will also work on this with the EPA next year.

With the information provided by the studies, I will develop and circulate a draft proposal for an international program for energy-efficient copiers, fax machines and possibly other multi-function equipment. This will include a description of criteria, goals to be reached and testing methodologies to be used. Use of the test procedures in developing this international program is essential. Internationally recognized procedures will avoid varying accounts of energy and power consumption of a machine. If information for a particular machine varies, users will find the information meaningless.

COPEE's testing and information program will address the ways of providing information on energy efficient technologies to users. With the use of the ASTM procedures, certain data can be obtained; how to present this data to the parties most interested in such results will be the focus of future study. Addressing the information needed from a computer test procedure will also be the focus of future work. I will work with them on both of these issues.

Besides the future work that I will perform, there are several other issues that need to be addressed. Reliability of equipment is an important issue. Miteff (1991) performed a study of the reliability of monitors and copiers. So far as I am aware, there have been no such studies for fax machines, personal computers and printers. In some way, the reliability of a personal computer when it is cycled frequently can be addressed through the reliability of laptop and notebook computers. A study could be performed, or even a survey taken from users and manufacturers, to determine the frequency of failure of the machine, and where the reliability issues are most prevalent.

Another issue that needs to be addressed is with the energy use of the materials used to produce office equipment. Energy issues associated with production of floppy disks, ink and toner used for imaging equipment, and the related amount of ink or toner each machine uses are just some of the areas of possible future study. This study could be related to the study included in Chapter 3, section IV.A, and to energy issues associated with recycling or reusing the equipment. Transportation energy costs could be included, as well as the operation of machinery associated with recycling. Energy benefits from recycling equipment could be compared to the overall energy losses associated with the machine.

References

Adam, J. 1993. "Applications, Implications," *IEEE Spectrum*. March.

Aebischer, B. 1992. "Utilisation Rationnelle de l'Electricite URELEC, Industrie et Tertiaire." Conference Franco Suisse, Bern.

Aebischer, B. 1993. ETH, Zurich. Personal communication.

Alford, R. C. 1992. "CPU Choices." BYTE, Special Issue on Portable Computing, Vol.. 17, No. 13. p. 19.

ASTM (American Society for Testing and Materials). 1982, Reapproved in 1987. "F757, Standard Test Method for Determining Energy Consumption of Copiers and Copier Duplicating Equipment." Philadelphia, Pa. Currently being revised by the author, C. Dandridge.

ASTM Standardization News. August, 1993. "Paper Recycling, Responding to the Mandate."

Becker, K. H. 1993. "Ermittlung von Planungsvorgaben fur HKLE-Anlagen." Internationales Informationsmeeting fur "Insider", Zurich.

Bell, T. 1993. "Technology 1993," *IEEE Spectrum*. January.

British Standards Institute. 1993. "Specification for Environmental Management Systems."

Brown Vence and Associates. 1991. "Advanced Customer Technology Test Office Equipment Energy Efficiency Design for the Pilot Demonstration Project." San Francisco, CA.

Bundesamt fur Energiewirtschaft. 1993. "Die Heimlichen Stromfresser. Standby-Verluste von Buro- und Unterhaltungselekronikgeraten. Anhang A."

Business Week. 1992. October 5. p. 122E.

Buyers Laboratory. 1992. "Test Reports and Fact Sheets on Plain Paper Copiers." Buyers Laboratory, Inc. Hackensack, NJ.

BYTE 1991a. November. p. 74.

BYTE. 1991b. December. p. 252.

BYTE. 1992a. Outlook Edition.

BYTE 1992b. May. p. 42.

BYTE. 1992c. August. p. 253.

Cole, B. 1993. "The Technology Framework," *IEEE Spectrum*. March.

Comerford, R. 1993. "PCs and Workstations," *IEEE Spectrum*. January.

DeLaHunt, M. J. 1990. "Trends in Electricity Consumption due to Computers and Miscellaneous Equipment." *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, Washington, D.C.

Depp, S. W. and Howard, W. E. 1993. "Flat Panel Displays." *Scientific American*. March

Diablo 1992. Correspondence from W. R. Alling and B. Beck, Diablo Scientific Laboratories, Inc., Livermore, CA.

Eglowstein, H. 1993. "HP's Simple Laser." *BYTE*. June.

Environmental Consciousness. March 1993. Workstation study, MCC Workstation Final Report.

Farhar, Barbara. 1993. "Trends in Public Perceptions and Preferences on Energy and Environmental Policy." National Renewable Energy Laboratory, under contract from the Department of Energy. DE-AC02-83CH10093

Feibus, M. 1993. "P6 and Beyond," *PC Magazine*, June 29, p. 164.

Ferrone, Robert. Digital Equipment Corporation. 1993. Personal Communication.

Forrester, Hulon. 1993. "Recycling Cathode-Ray Tubes." *Information Display*. June.

France Telecom. 1989. "Electroluminescent Flat Panel Displays with Memory."

Friedman, P. S. 1990. "Plasma and EL Displays: the Efficiency War." *Information Display*, February, p. 9.

Giese, R. "Scoping Study Pulp and Paper Industry", EPRI report RP-2782-3, revision 1.
GSA 1993. "Energy-Efficient Microcomputers: Guidelines on Acquistion, Management and Use." General Services Administration, Information Resources Management Service. KAP-93-4-1.

Halfhill, T. 1993. "Intel Launches Rocket in a Socket." *BYTE*. May.

Harris, J. 1992. "Office Technologies and Energy: Background Briefing for the Federal Interagency Working Group on Energy-Efficient Office Technologies."

Harris, J. 1993. " U.S. 'Market-Pull' Strategies for Energy-Efficient Office Equipment." Internationales Informationsmeeting fur "Insider", Zurich.

Heid, J. 1993. "How to Buy a Color Printer." *Macworld.* May.

Hewlett Packard Corporation. 1993. "HP PCs and the Environment."

Hewlett Packard Corporation. 1993b. "How Hewlett-Packard Saves You Money and Energy--Today."

Hill, P. 1993. Personal communication.

Hitachi Technology. 1992. "World's Largest Memory Capacity 3.5-Inch and 5.25-Inch Disk Drives." Special Annual Issue of *Hitachi Review,* Hitachi Ltd., Tokyo, p. 19.

Howard, W. E. 1992. "Thin-Film Transistor/Liquid Crystal Display Technology--An Introduction." *IBM Journal of Research and Development,* Vol. 36, No. 1.

Hurlimann, B. 1993 "Efficient use of Electricity in Zurich's Commercial Sector." Internationales Informationsmeeting fur "Insider", Zurich.

Huser, A. 1991. "Quelle est la Consummation d'Electricite de la Bureautique?"

Huser, A., Eisenhut, H. and Bush, E. 1992. "Energieverbrauch von elektronischen Bürogeräten. Materialien zu RAVEL.

ICL. 1992a. "ICL Personal Systems." ICL, London.

ICL. 1992b. "Personal Ergonomics, Facts and Figures."

IEEE Spectrum.. "IC's Going on a 3V-Diet." May 1992 and Technology Forecast for Solid-State Devices January 1993.

Ilumura, T., Shibata, R. and Takada, Y. 1988. "Directly Heating Roller for Fuse-Fixing Toner Images." U.S. Patent 4,724,305.

Illuminating Engineering Society. 1981. *Lighting Handbook, Reference Volume.* p. 1-13.

Intel Corporation. 1993. "Energy Efficient Desktop Personal Computers," report to J. Roturier, Bordeaux University, Gradignan, France.

Intel/Microsoft. 1992. "Advanced Power Management: Extending Battery Life and Productivity in Personal Computing." Technical Background prepared by Intel and Microsoft.

Jensen, J. B. 1993. DEFU, Lyngby, Denmark. Personal communication.

Johnson, B. J. and Zoi, C. R. 1992. "EPA Energy Star Computers: The Next Generation of Office Equipment."

Jones, M. 1989. "NEC Breaks New Ground with First Color Portable." *PC Magazine,* October 31, p. 33.

Kardon, D. 1989. "Electroluminescent Backlights for Liquid-Crystal Displays." *Information Display*, February, p. 17.

Knecht, F. 1993. "Swiss Bank Corporation's Environment Strategy: The Strategy and the First Year of Implementation." Swiss Bank Corporation, Coordination Center for Ecology, Basel, Switzerland.

Knickerbocker, B. 1993. "The Recycling Payoff in Energy-Tax Plan." *The Christian Science Monitor,* June 7.

Kobb, B. 1993. "Personal Communications Services." IEEE Spectrum. June.

Koomey, J. G., Oey, T. and Bergman, E. 1992. "The Economics of Cycling Personal Computers." Lawrence Berkeley Laboratory draft report LBL-32133 UC-350.

Kurtz, R. 1993. Program Specialist, Ontario Hydro. Toronto, Canada.

Lebot, B. 1993. ADEME, France. Personal communication.

Ledbetter, M., Smith, L. 1993. "A Guide to Energy-Efficient Office Equipment." EPRI TR-102545; ACEEE, Berkeley, California.

Legg, G. 1993. "Flash Memory Challenges Disk Drives," EDN. February 18.

Lovins, A. B. and Heede, R. 1990. "Electricity-Saving Office Equipment." Competitek report. Rocky Mountain Institute, Snowmass, CO.

Memory Card, Systems and Design. November/December 1992a. "1992: PC Card Market Finally Ready for Takeoff."

Memory Card, Systems and Design. November/December 1992b. "PCMCIA Interfaces: The Common Denominator in Mobile Computing Storage Devices."

Michaels, H. and DaSilva, J. 1990. "Electronic Equipment Load Growth." *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings,* American Council for an Energy-Efficient Economy, Washington, D.C.

Mills, E. 1991. "Evolving Energy System: Technology Options and Policy Mechanisms." Department of Environmental and Energy Systems Studies, University of Lund, Sweden.

Miteff, L. and Winter, T. 1991. "Standby-Leistungsverbrauch-Reduzierung und Ihre Auswirkung auf die Zuverlassigkeit des Telefax-Gerats Panafax UF-150." ETH (Swiss Federal Institute of Technology), Zurich.

Murdoch, J. 1985. *Illuminating Engineering, From Edison's Lamp to the Laser.* Macmillan Publishing Company, New York.

Nadel, B. 1993. "The Green Machine." *PC Magazine,* Volume 12, Number 10. May 25.

Nordman, B. 1991. "Energy Use, Printers, Copiers, and Paper." Lawrence Berkeley Laboratory draft report.

Norford, L. K., Dandridge, C. B. 1993. "Near Term Technical Assessment of Energy Efficiency in Office Technology", Massachusetts Institute of Technology. To be published in EPRI report and to appear in IEEE Conference Record of the 1993 IEEE Industry Applications Society Annual Meeting, October 1993. Toronto, Canada.

Norford, L. K., Hatcher, A., Harris, J. P., Roturier, J., and Yu, O. 1990. "Electricity Use in Information Technologies." Annual Review of Energy, Vol. 15:423-53

Norford, L. K., Rabl, A., Harris, J. P., and Roturier, J. 1988. "The Sum of Megabytes Equals Gigawatts: Energy Consumption and Efficiency of Office PC's and Related Equipment." *Proceedings of the ACEEE 1988 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, Washington, D.C.

NUTEK (National Board for Industrial and Technical Development). 1992. "Energy Efficiency in Office Equipment." Department of Energy Efficiency. Stockholm.

NUTEK 1993. "One Watt After One Hour in One Year." Department of Energy Efficiency. Stockholm.

Office of Technology Assessment (OTA), U.S. Congress. October 1992. "Green Products by Design: Choices for a Cleaner Environment", OTA-E-541.

Ordinance 1993. "Appendix 11 to the Ordinance on the Use of Energy." Draft dated 28 June, 1993. Swiss Federal Office of Energy.

PC Magazine. 1992. August. p. 315.

PC Magazine. 1993. March 16. p. 124.

PC&C Research Corporation. 1993. Promotional literature for the "extra-green" Iguana computer. Camerillo, CA.

Perry, T. S. 1993. "Cleaning Up." *IEEE Spectrum*. February.

Piette, M. A., Eto, J. and Harris, J. P. 1991. "Office Equipment: Energy Use and Trends." Lawrence Berkeley Laboratory report LBL-31308.

Potts, M. 1992. "Rethinking Computers, Companies." Washington Post, November 4, page F1.

Power Quality Testing Network. 1993. "Test Protocol for System Compatibility." Draft report for EPRI.

Pratt, R. G., Williamson, M. A., and Richman, E. E. 1990. "Miscellaneous Equipment in Commercial Buildings: the Inventory, Utilization, and Consumption by Equipment Type." *Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, Washington, D.C.

Prechtl, H. 1993. "Stand-by Losses of Office and Consumer Electronics Equipment." Internationales Informationsmeeting fur "Insider", Zurich.

Rebsdorf, A. 1993. Research Association of Danish Electric Utilities (DEFU). Personal communication.

Reinhardt, A. 1993. "Video Conquers the Desktop," *BYTE*. September.

Reinhardt, A., Perratore, E., Redfern, A., and Malloy, R. 1992. "The Greening of Computers." BYTE, September, p. 147.

Roturier, J. 1992. "SSC Stand-by Modes: A Step Towards Energy Efficient OAs." Centre d'Etudes Nucleaires de Bordeaux-Gradignan, Gradignan, France.

Ryan, T. and Anwyl, E. 1993. "Display Power Management Activities." Video Electronics Standards Association, San Jose, CA.

Sands, B. 1990. System Design: an 18-in. Flat-Panel EL Monitor." *Information Display*, February, p. 13.

Schlam, E. 1989. "Electroluminescent Displays." *Information Display*, December, p. 10.

Schmitz, R. 1993. "Standards and Target Values in Switzerland." Internationales Informationsmeeting fur "Insider", Zurich.

Self, K. 1993. "Solid State," *IEEE Spectrum*. January.

Seymour, J. 1993. "The Next Standard." *PC Magazine*, June 29, p. 108.

Smarte, G. and Baran, N. 1988. "Face to Face." BYTE, September, p. 243.

Tannas, L. E.. Jr. 1992. "Japanese Flat-Panel Displays: What JTEC Saw." *Information Display*, July/August, p. 18.

Tannas, L. et al. 1992. "Display Technologies in Japan." Japanese Technology Evaluation Center report to NSF, DARPA, and Department of the Air Force.

TCO (The Swedish Confederation of Professional Employees) 1992. "Environmental Labeling of Display Units." Third International Scientific Conference, Work With Display Units (WWDU), Berlin.

Tiller, D. K. and Newsham, G. R. 1992. "Desktop Computers and Energy Consumption: A Study of Current Practice and Potential Energy Savings." Institute for Research in Construction, National Research Council of Canada, Ottawa, Ontario.

U.S. State Department. April 1992. "U.S. Views on Global Climate Change." Presented at United Nations prior to the U.N. Framework Convention on Climate Change.

Van Name, M. and Catchings, B. 1990. "Competing Color LCD Display Technologies." BYTE, April, p. 148.

Vaudaine, Meyer. 1991. "'Microtips' Fluorescent Display." Report for IEDM 1991.

Von Stroh, R. 1988. "Electroluminescent Displays." *Information Display*, December, p.14.

Watkins, L. 1988. Technical Marketing Case Study." *Information Display*, May, p. 20.

Weber, L. F. 1989. "Plasma Displays in Their Twenty-Fifth Year." *Information Display*, December, p. 12.

Western Digital Corporation. 1993. Product literature for Caviar series of hard disk drives. Irvine, CA.

Wirth, T. 1992. Buyers Laboratory, Incorporated, Hackensack, New Jersey. Personal communication.

Zorpette, G. 1993. "Large Computers," *IEEE Spectrum*, January.

Appendix

Appendix A

Interim Test Method for Copiers

Assumptions:

A typical month is 30 days.
A typical work month is 22 days.
A typical work day is 9 hours.
10% of the copiers are left on over night.
Energy savers, if present, are in use for 50 percent of idle time.
Given the above, a machine is on 231 hours/month.

1. Plug-In Energy per Month

1.1.1 Assuming the machine is plugged in 30 days/month and 24h/day and operating 231 hours per month, compute plug-in time/month:
(720 hours/month plugged in) - (231h/month on) = 489 h/month

1.1.2 Compute the energy, in Wh/month for plug-in:
(489 h/month)*(Plug-in power)

2. Warm-up Energy per Month

2.1.1 Due to assumption #1, the number of times the machine is turned on is calculated by 22 work days per month minus 10%, which is 20 times per month. Warm-up time/month is calculated by the following equation:
(20 times/month)*(warm-up time [in hours])

2.1.2 Compute the Wh/month for warm-up:
(2.1.1)*(Warm-up power)

3. Print Energy per Month

3.2.1 and 3.2.2 were used if ASTM data was available; if not then 3.1.1 and 3.1.2 were used.

3.1.1 Compute the number of copy-hours per month by the following equation:

(Monthly volume)/[(copy speed, including first copy)*(60 min/hour)]

The monthly volume should be the same for all copiers in a class comparison.

3.1.2 Compute the Wh/month for copying:

(3.1.1)*(Printing power)

3.2.1 Use the number provided by ASTM data for copying energy per copy.

3.2.2 Compute the Wh/month for copying:

(3.2.1)*(Monthly volume)

4. Idle Energy per Month

4.1.1 Use the following equation to calculate the amount of time the machine is idling, in energy-saver mode or copying:

[(231 h/month) - 2.1.1]

Use the above expression and 3.1.1, to compute the time the machine is idling:

$$\frac{\{[(231\ h/month) - 2.1.1] - 3.1.1\}}{2}$$

4.1.2 Compute the Wh/month for idle mode:

(4.1.1)*(Idling power)

5. Energy-Saver Energy per Month

5.1.1 The time the copier is in energy-saver mode is the same as 4.1.1.

5.1.2 Compute the Wh/month for energy-saver mode:

(5.1.1)*(Energy saver power)

6. Total Energy per Month

6.1.1 Compute total Watt-hours per month by adding 1.1.2 through 5.1.2. In the case that there was ASTM energy/page data available, 3.2.2 was used instead of 3.1.2.

7. Total Energy per Page

7.1.1 Compute total Watt-hours per page by dividing 6.1.1 by the copy volume.

Appendix B

Assumptions:

The assumptions are precisely those we listed for calculating copier energy. We note, in support of the assertion that 10 percent of printers are left on overnight, that BVA (1991) observed a slightly higher percentage among 39 laser printers.

1. Plug-In Energy per Month

No data are available and we assume a value of 0 W.

2. Warm-Up Energy per Month

No data are available and we assume that warm-up requires no more energy than standby.

3. Print Energy per Month

3.1.1 Compute the number of copy-hours per month by the following equation:

(Monthly volume)/[(copy speed, including first copy)*(60 min/hour)]

The monthly volume should be the same for all copiers in a class comparison.

3.1.2 Compute the Wh/month for copying:

(3.1.1)*(Printing power)

4. Idle Energy per Month

4.1.1 Use the following equation to calculate the amount of time the machine is idling, in energy-saver mode or copying:

[(231 h/month) - 2.1.1]

Use the above expression and 3.1.1, to compute the time the machine is idling:

$$\frac{\{[(231\ \text{h/month}) - 2.1.1] - 3.1.1\}}{2}$$

4.1.2 Compute the Wh/month for idle mode:

(4.1.1)*(Idling power)

5. Energy-Saver Energy per Month

5.1.1 The time the copier is in energy-saver mode is the same as 4.1.1.

5.1.2 Compute the Wh/month for energy-saver mode:

(5.1.1)*(Energy saver power)

6. Total Energy per Month

6.1.1 Compute total Watt-hours per month by adding 3.1.2 through 5.1.2.

7. Total Energy per Page

7.1.1 Compute total Watt-hours per page by dividing 6.1.1 by the copy volume.

Appendix C

Table 3.19. Breakdown of Thermal and Electrical Energy usage in Pulp and Paper Process

Process	Thermal kWh/ton	Electrical kWh/ton	Total kWh/ton
Barking	0	4.4 - 7	4.4 - 7
Chipping	0	7.6 - 10	7.6 - 10
Pulping	900 - 1025	15 - 30	915 - 1025
Pulp dryer	1025 - 1500	36 - 60	1025 - 1560
Causticizing	1300 - 1500	12 - 18	1312 - 1518
Washing	150	9 - 15	159 - 165
Refining	300 - 700	60 - 120	360 - 820
Bleaching	90 - 2700	24 - 150	114 - 2850
Paper machine	190 - 360	90 - 120	190 - 480